4. The Lower Ordovician Limestones between the *Ceratopyge* Shale and the *Platyurus* Limestone of Böda Hamn

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With a Description of the Microlithology of the Limestones

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Contents

Introduction

The present paper forms part of a description of a core from a boring at Böda hamn. The lower parts of that core comprising Cambrian and Tremadocian (*Ceratopyge*) beds were described by WÆRN (1952) and HESSLAND (in print). The Lower Ordovician above the *Ceratopyge* shale is in Öland exclusively developed as bedded limestone.

The part of the Böda hamn core dealt with below comprises the beds from the Upper "*Planilimbata*" limestone up to and including the *Gigas* limestone of the Swedish stratigraphical sequence, thus including the following divisions:

(*Platyurus* limestone)
Gigas and *Obtusicauda* limestones
Limestone with *Asaphus* "*raniceps*"
Limestone with *Asaphus expansus*
Limestone with *Asaphus lepidurus*
Limestone with *Megalaspis limbata*
Upper "*Planilimbata*" limestone
(*Ceratopyge* shale)

These divisions largely correspond to the Lower Llanvirn and Upper Arenig; according to an oral communication by Dr. TJERNVIK the lowermost part of the Arenig seems to be missing in N. Öland.

In the core these limestones occupy the portion between the levels 23.42 m and 39.15 m below the local surface. The *Gigas* and *Obtusicauda* limestones are red like most of the *Platyurus* limestone but of a somewhat lighter shade. The lowermost part of the *Platyurus* limestone (*c.* 1,5 m) can, however, hardly be distinguished from the *Gigas* limestone neither by colour nor by petrographical characters of any kind. But at the level (23.42 m) which has here been taken as the *Platyurus–Gigas* boundary, the limestone below the boundary (*c.* 5 cm) is almost purely grey, whereas the limestone immediately above is red, with an intensity of colour usually met with at considerably higher levels of the *Platyurus* limestone.

The fossils of the core are too sparse to permit the exact establishment of the zone boundaries,[1] but all the species of *Megalaspis*, characteristic of the zones distinguished earlier (BOHLIN 1949), have been found; only *M. obtusicauda* (see p. 131) is subject to some doubt.

The observations on the core corroborate the results obtained from the study of the surface exposures; further, they give an idea of the thickness of the various zones, though the thickness of the individual zones seems to vary within rather wide limits in Northern Öland.

In the present paper, notes on some recent field work which is of importance for the interpretation of the core are found.

This paper was prepared at the Paleontological Institution of Upsala, in close cooperation with students working on other divisions of the core.

My sincere thanks are due to Prof. P. THORSLUND who has made every possible effort to facilitate my work in the field as well as at the institution. He has also read the first half of my manuscript.

In addition, I wish to thank Dr. V. JAANUSSON with whom I have discussed almost everything connected with the present paper in order to obtain the greatest possible uniformity in the treatment of the calcareous upper part of the core, and from whom I have obtained much valuable advice. He has also arranged for and supervised the mechanical analyses of the division of the core here described and prepared and described the diagrams on which the results of the analyses were plotted (pp. 153—168; Text Figs. 10—14).

My thanks are further due to Dr. T. TJERNVIK who has kindly put at my disposal his rich collections from Nerike and other localities, as well as specimens borrowed by him from other museums, among them some of DALMAN's specimens of *Niobe laeviceps*. His experience of the lowermost members of the Orthoceratite limestone has been of great help in my work on the parts of the core containing *Megalaspis limbata* and *M.* aff. *planilimbata*.

Description of the Core

23.42—25.27 (*m*)[2]: *Gigas* and *Obtusicauda* limestone.

Variegated limestone. Main colour pale reddish brown; everywhere, however, portions of greyish green colour, sometimes occupying as much as 50 per cent of the rock, or even more as in the uppermost part (see above). As seen in Pl. I, Fig. 1, the distribution of colour displays a certain regularity: in each bed the grey colour dominates in the lower part; higher up the red colour comes in, and intensifies gradually upwards; sometimes it disappears again a little below the upper surface of the bed, the grey

[1] No attention was paid to microfossils.

[2] The letters in brackets refer to the macrolithologically determined divisions in JAANUSSON's microlithological description. See also Text Figs. 2 and 3.

again dominating, as between *A* and *B* in the fig. In some portions the variegation may, at first sight, appear to be quite irregular; a more or less abrupt change of colour at the contact between two beds can, however, be seen on closer examination (Pl. I, Fig. 2). See also p. 121.

The limestone of some beds is traversed by fine branching tubes forming the centre of the grey portions (Pl. I, Fig. 2, between *A* and *C*).

The upper part of this core portion undoubtedly belongs to the *Gigas* limestone. Below 24.00 m no fossils characteristic of the *Gigas* limestone were found; still, the following 125 cm must consist of *Gigas* limestone and probably also *Obtusicauda* limestone, although the exact boundary between the two zones cannot be drawn.

Fossils from the *Gigas* limestone: *Pliomera fischeri* (EICHW.) (24.05), *Megalaspis gigas* ANG. (23.89—24.00). *Asaphus* sp. (? 24.20), *Pseudasaphus perstriatus* n. sp. (23.60; see p. 138), *Cyrtendoceras vaginatum* (SCHLOTH.) (23.70—25.00), *Orthambonites* sp. (23.95), Orthoid brachiopods (23.80, 23.85).

From the part designated as the *Obtusicauda* limestone poor remains of two large pygidia, possibly of *M. obtusicauda* n. sp. (cf. p. 131), were recovered at level 25.20 and a fragment of an orthoceracone cephalopod at 25.15.

25.27—30.83 (*j*—*l*): Limestone with *Asaphus* "*raniceps*".[1]

In my paper of 1949 this limestone was divided into three divisions, based mainly on petrographical differences. The same divisions can be easily recognized in the core.

α) 25.27—26.60 (*l*): Greyish brown with almost purely grey portions. The variegation resembles that met with in the *Gigas* limestone, only the red brown colour has faded into a very pale brown. The limestone contains grains, varying in colour (from brown to almost black) and in frequency, but evidently confined to the greyish brown portions of the rock. In the *Gigas* limestone similar grains of a redbrown colour are confined to the more or less reddish matrix and are never seen in the gray portions.

Fossils: Fragments of trilobites, probably most of them of *Megalaspis rudis*, abound in 4 portions: 25.58—25.66, 25.79—25.82, 25.94—26.05, 26.20—26.27.

The following forms were recognized: *Megalaspis* cf. *rudis* ANG. (25.30—26.55), ? *Pseudasaphus* sp. (25.36), *Lycophoria* sp. (? 26.05), Orthoid brachiopods (25.75—26.35), *Cyrtendoceras vaginatum* (SCHLOTH.) (25.30—26.27), Orthoceracone cephalopods (26.45—25.57).

β) 26.60—27.79 (*k*): Light grey limestone. No brown grains and no grains of glauconite. Rich in fossils between 26.60 and 27.14 m.

[1] *sensu* ANGELIN; see JAANUSSON & MUTVEI 1953, p. 406, footnote 1.

Fossils: *Celmus granulatus* ANG. (26.75),[1] *Pliomera fischeri* (EICHW.) (26.65—28.60), *Megalaspis* cf. *rudis* ANG. (26.66—27.70), *Asaphus "raniceps"* (26.90—28.60), *Pseudasaphus* cf. *duplicatus* n. sp. (26.60, 26.68; see p. 141), *Iru* cf. *zonata* (DALM.) (28.50), *Ahtiella* sp. (27.55, 27.79), Orthoid brachiopods (10 specimens between 26.70—28.50), *Cyrtendoceras vaginatum* (SCHLOTH.) (? 27.70), Orthoceracone cephalopods (26.70—28.35).

γ) 27.79—30.83 (*j*): Light greyish brown limestone, fairly uniform in colour. Contains grains of glauconite. At the highest levels the glauconite grains are quite small and scattered. The amount of glauconite increases downwards, but is never as great as in the *Expansus* limestone (see below), and the limestone takes on a bluish rather than a brownish tint. At all levels light-brown spots can be seen; at some levels subordinate corrosion surfaces seem to have a thin veneer of light-brown colour. In some parts there are diffusedly delimited brownish tubes, in which the limestone is very fine-crystalline, in obvious contrast to the rather coarse grained bulk of the rock.

The lower limit of the "*Raniceps*" limestone cannot be drawn with certainty but it was put at 30.83 m, below which level a marked increase in the amount of glauconite occurs. A little below this level a partial pygidium of *Megalaspis acuticauda* was found. This boundary agrees with that at other localities in Northern Öland where the *Expansus* limestone is usually richer in glauconite grains than the "*Raniceps*" limestone.

Fossils: ? *Cyrtometopus* sp. (29.70), ? *Pliomera fischeri* (EICHW.) (29.00), *Megalaspis* cf. *rudis*. ANG. (28.90, 30.51), *Asaphus "raniceps"* (28.80—30.65), ? *Pseudasaphus globifrons* (EICHW.) (28.85, 29.70; see p. 142), *Illaenus aduncus* JAANUSSON (29.10, 29.75), *Orthambonites* sp. (30.51), *Antigonambonites* sp. (29.05), *Ingria* sp. (29.80), Orthoceracone cephalopods (29.55).

30.83—31.83 (*g*—*i*): Limestone with *Asaphus expansus*.

Dark grey limestone usually rich in glauconite. In the upper part the glauconite is irregularly distributed, in such a manner that beds so rich in glauconite as to affect strongly the colour of the limestone alternate with beds in which the glauconite is more scarce. Between 31.10 and 31.21 m small groups of white ooliths were found. The limestone contains lighter portions arranged in the same way as the light-brown portions of the lower part of the "*Raniceps*" limestone described above, but standing out more distinctly than there because the matrix is darker in colour. Downwards the amount of glauconite increases, and the middle part of the *Expansus* limestone is formed by glauconitic sand (31.40—31.46 m = *h*). This accumulation of glauconitic has a fairly sharp limit towards the bed following below, which is only a few cm thick, conglomeratic, containing fragments

[1] The same form was listed in 1949 (p. 566) as ? *Cyrtometopus* sp.

of light coloured limestone in a matrix very rich in glauconite. Below 31.53 the bed is dark-coloured from its contents of glauconite, which is here more evenly distributed than between 30.83 and 31.40 m.

Fossils: ? *Cyrtometopus* sp. (31.50), *Megalaspis acuticauda* ANG. (30.90, 31.00, ? 31.53), *Asaphus* sp. (30.95, 31.00), *Illaenus sarsi* JAANUSSON (30.95), *Ahtiella* sp. (31.05), Orthoid brachiopods (31.67, 31.75).

31.83—34.86 (*e*, *f*): Limestone with *Asaphus lepidurus*.

The uppermost 0.35 m might be considered as transitional to the beds above. It contains a series of surfaces, appearing on the polished surface as sharp, irregular lines between a lower very light brown or almost white limestone and an upper grey limestone (*A*—*F* in Pl. II, Fig. 1). The amount of glauconite is about equal on both sides of such a line, although a slight concentration of glauconite above the line can be noted. At some levels a very thin marly lamina is intercalated between two limestone beds, e.g. at *b* in Pl. II, Fig. 1. The portion of the core at *a* in this figure consists of a breccia of limestone fragments almost *in situ*, cemented by a network of marly laminae rich in glauconite. Between 32.18—34.33 the limestone is grey and very homogeneous. Below 34.33 the limestone is alternately reddish and grey, so that in a bed a more or less marked change of colour takes place, usually from grey below to reddish brown above. The upper surface of each bed is covered with a thin film of limonite. This red and grey limestone forms JAANUSSON's division *e*. In some parts glauconite grains are very scarce, but at certain levels of the grey limestone they are as abundant as above 32.18.

In colour and structure the division *e* resembles the lower parts of the *Limbata* limestone. The upper limit of the *Limbata* limestone is, however, put at 34.86, where there is a marked change in colour at an irregular surface, the limestone above the surface being greyish red, that below deep red in colour. Immediately above the contact there is a confusion of irregular surfaces, in places with small accumulation of glauconite. Sections of small fragments of limestone are seen in cavities of the surfaces (Pl. II, Fig. 2).

Fossils are rare, and quite insufficient for a subdivision of this part of the core into different faunal zones. The list comprises the following forms: *Megalaspis hyorrhina* v. LEUCHTENB. (? 32.30, 33.55; Pl. III, Fig. 10), *Asaphus* sp. (34.45), *Ptychopyge excavato-zonata* ANG. (32.25), *Nileus armadillo* DALM. (34.60), *Ampyx* cf. *nasutus* DALM. (33.95), *Antigonambonites* sp. (31.85), *Lycophoria* sp. (32.85), Orthoid brachiopods (31.85—34.35), *Acrotreta* sp. (33.00). Orthoceracone cephalopods (32.30).

34.86—38.08 (*c*, *d*): Limestone with *Megalaspis limbata*.

The intensely red colour below the sharp limit towards the *Lepidurus* limestone reaches down to 35.73 m. The greyish green colour is in this part restricted to scarce narrow "tubes". Below 35.73 the colour is much paler, and within a bed it changes from grey to red in the same way as in the lower part of the *Lepidurus* limestone (Pl. II, Fig. 3). In the lowermost part the marly laminae intercalated between the limestone layers are thicker than in the higher parts. Between *c.* 36.85 and 36.95 there is a repetition of more intensely red laminae, undoubtedly representing the "Blood Layer", in Swedish "Blodläget", which occurs in this part of the sequence all over Northern Öland (BOHLIN 1949, p. 532 ff.). There is no glauconite in the *Limbata* limestone.

Fossils: *Megalaspis limbata* var *lata* TÖRNQ. (36.65), *Megalaspis* sp. (37.15), ? *M. limbata* (BOECK) var. indet. (37.40; Pl. V, Fig. 1), *Nileus armadillo* DALM. (35.40—37.55), *Niobe imparilimbata* n. sp. (37.40; see p. 148), Orthoid brachiopods (35.00—37.45), Orthoceracone cephalopods (34.95, 36.65).

38.08—39.15 (*a*, *b*): Upper "*Planilimbata*" limestone.

The boundary between the *Limbata* limestone and the Upper "*Planilimbata*" limestone is marked by a surface coated with glauconite and rich in corrosion pits. The uppermost bed evidently corresponds to a bed that workers in the quarries on the western coast of the island name "Blommiga bladet" ("Flowery Layer;" BOHLIN 1949, p. 534). This shows a variegation of red and ochre from different iron compounds and contains the type of corrosion surfaces described above.

The upper part of the Upper "*Planilimbata*" limestone resembles the lowermost part of the *Limbata* limestone. The marly portions are in both divisions dark grey, but the more calcareous layers of the Upper "*Planilimbata*" limestone are purely grey without reddish tints. In some portions, especially those between 38.33—38.70, the limestone contains branching tubes with a filling that is dark brown at the walls and grey in the centre. Such tubes were observed also in exposures on the western coast (Text Fig. 1). Nothing similar is known from higher divisions of the limestone sequence in Northern Öland, and hence these markings seem to be characteristic of a certain part of the Upper "*Planilimbata*" limestone.

Between 38.85—39.08 the limestone is compact. This portion is not homogeneous, however. At 38,87 there is a surface marked by a thin greenish film, probably of glauconite, and a slight accumulation of glauconite grains. Above the surface the limestone is grey, below the surface it is brown for about 1 cm, then the colour rapidly changes downwards into grey. At 39.00 glauconite suddenly becomes abundant, but below 39.04 there is again

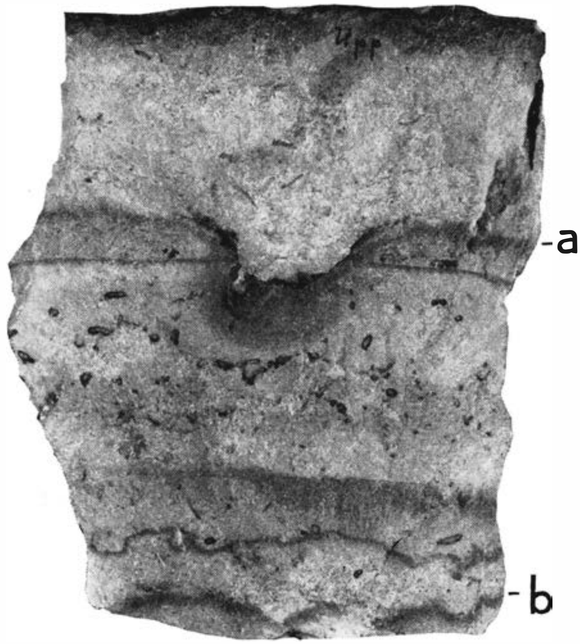


Fig. 1. Sample from bed near the bottom of the Upper "*Planilimbata*" limestone. Dark portions brown, light portions grey, with intermediate shades. At *a* and *b* a thin film of glauconite; a couple of cm below *a* richly glauconitiferous limestone follows. Dark spots between *a* and *b* sections through winding tubes, dark brown with grey centres (see p. 117). From the shore about 1.5 km S. of Sandvik (Persnäs). × 2/3.

very little glauconite. The basal portion of the Upper "*Planilimbata*" limestone consists of about 4 cm glauconite sand with a rather diffuse upper delimitation marked by fragments of limestone in a richly glauconitiferous matrix. The contact surface towards the underlying *Ceratopyge* shales is sharp but very irregular.

Fossils: *Euloma* sp. (38.30), *Megalaspis* aff. *planilimbata* ANG.[1] (38.22, 38.29), *Megalaspides dalecarlicus* (HOLM) (38.60, 38.80), *Nileus armadillo* DALM. (38.55—38.90), *Niobe* sp. (? 38.29); Orthoid brachiopods (38.08—38.80), *Acrotreta* sp. (38.30—38.80).

General Remarks on the sediments

In 1949 I tried to show that the sediments forming a limestone layer must have been laid down within a very short time, probably within a few hours. This is still my opinion, and I have not found anything contradictory to this theory during my studies of the core. Indeed, a vertical position of large fossils—the fact on which my conclusions were mainly based—was observed at several levels all through the length of the core.

[1] Identical with the younger form of *M. planilimbata* ANG. in TJERNVIK 1952.

Fig. 1 A. Part of a thin section through the red *Limbata* limestone. Deep boring at Böda hamn, approximately at 35.00 m (sample between 34.97—35.01 m). × 4. See below.

There are also microstructural features of the beds that argue in favour of this theory. If the deposition of the limestone material was slow and only a fraction of millimetre was deposited every year, one would expect to find a fine lamination marked by differences in colour, in the size of the grains, or in the frequency of fossil fragments. It is inconceivable that exactly the same chemical and mechanical conditions should prevail through the long span of time needed for a slow accumulation of several cm of limestone. The beds never show such a lamination. Further, the distribution of fossil fragments repeats on a small scale what was observed on the larger fossils. Fragments a couple of mm in length are often oriented at right angles to the bedding planes; there are peculiar concentrations of fragments in certain portions, whereas close by at the same level fragments are scarce, and one is under the impression that there was a rather strong turbulence during the deposition (Text Fig. 1 A). Especially noticeable is the dark stripe to the left in the figure penetrating deeply, 1 cm or more, into the bed. It contains fewer fossil fragments than the surroundings and those present are oriented largely parallel to the sides of the stripe. What else can this be than the evidence of a whirl carrying a sediment rich in fragments into a flow of less fossiliferous matter? There is no sharp limit between the two types of limestone and thus these were evidently deposited contemporaneously. The plug of richly fossiliferous limestone to the left in the figure has a vertical diameter of about 2 cm.

Between the limestone layers there are often lamellae of marly limestone of varying thickness very likely representing periods of slow sedimentation, but, just as often, fresh limestone material was laid down on the corroded surface without any marly intercalation. In the latter case there is often a concentration of glauconite above the corroded surface (Pl. II, Fig. 1). Further, two beds separated by such a surface are firmly soldered together, whereas two beds separated by even a very thin marly lamella can be easily split apart, though they are often held together by richly developed stylolites.

Surfaces without a marly film occur everywhere. Especially noticeable are those mentioned from the uppermost part of the *Lepidurus* limestone (p. 116). Such surfaces stand out as white bands on the walls of a quarry at Gillberga where they occur in the uppermost 125 cm of the limestone from a level 340 cm above the "Blood Layer" and upwards. The limestone containing white surfaces is separated from the typical non-glauconitic *Limbata* limestone by about 160 cm of limestone with some glauconite. In the core the white bedding planes occur within a thickness of 35 cm, 470 cm above the "Blood Layer" and 270 cm above the supposed *Lepidurus-Limbata* boundary, where scattered grains of glauconite begin to appear (p. 121). White surfaces were also observed in the waste material around the water-filled quarry on the alvar at Stenninge where about 6 m of limestone are exposed, downwards from a bed of typical Jordhamn limestone (BOHLIN 1949, p. 544[1]). These surfaces may be of some importance for the correlation of sections in Northern Öland. Their value must, however, be checked during more extensive field work.

The distinctly coloured "Blood Layer" is well developed in the core. This characteristic bed has up to now been followed for a distance of 70 km from Byxelkrok in the north as far south as to the parish of Högsrum where it occurs in several quarries north of the church. At Köping it occurs near the summit of the "Klint".

On the other hand, the colour of other parts of the *Limbata* limestone varies. In the core the portion following below the glauconitiferous limestone is intensely red, in the parts farther down limestone of a pale red colour alternates regularily with grey limestone (see below). The Upper "*Planilimbata*" limestone is grey. At Köping, and also at other localities along the western coast, the pale red and grey beds overlie beds of intensely red colour, the contact lying at Köping about 2 m below the "Blood Layer".

The so-called "Flowery Layer" is here interpreted as marking the uppermost part of the Upper "*Planilimbata*" limestone. In the core the limestone is grey, not ochre-coloured nor red as on the western coast (cf. p. 117), but to judge from the fossils there seems to be no doubt about the correlation. The branching tubes of the Upper "*Planilimbata*" limestone (p. 117) are

[1] The name *Hjorthamn* is used on the topographical maps. The correct name is *Jordhamn.*

apparently another feature that can be used for identifying these beds in the field in N. Öland.

In the parts of the core where red and grey colours alternate each bed is grey below and red above, the colours grading into each other, but this rhythm is often disturbed by other phenomena, for instance by grey tubes penetrating from above into the red portions. This is especially the case in some parts of the *Gigas* limestone (cf. Pl. I, Figs. 1 and 2).

The changing of the colour described above may be interpreted in various ways. One may hold that a gradual change from a reducing to an oxidizing medium may have occurred during the deposition of the sediments. If, however, the beds were suddenly laid down, this explanation is of course excluded. The original colour of the beds may have been red, and grey colours, wherever they occur, may then be due to a reduction through organic matter. The very gradual transition between the colours seems, however, to be easiest explained by assuming that the sediment was originally grey and afterwards submitted to an oxidation that penetrated to various depths, according to the time of exposure before the deposition of the overlying bed. The grey tubes in the red portion of the bed must be due to decaying organic matter from worms and other animals living in the bottom sediments. This may have counteracted the oxidation or caused a secondary reduction of the red iron compounds.

Notes on the Boundaries between the Major Divisions

In the description of the core the limit between larger stratigraphical units has in some cases been put where some marked changes in the sedimentation are indicated. Thus a well-marked contact surface at the top of a series of deep-red limestone beds was taken as the upper limit of the *Limbata* limestone (34.87 in the core). Above this level, however, there is nearly 1 m of limestone in which no characteristic fossils were found. The part of this limestone, below 34.33, shows alternating grey and red colours as in the lower part of the *Limbata* limestone, the only difference being the presence of macroscopic glauconite in the higher beds. These latter may belong to the *Limbata* limestone; the upper limit of the *Limbata* limestone may even lie as high up as at 34.15 where a fairly well-marked contact surface occurs.

Also the upper limit of the "*Raniceps*" limestone is uncertain. My interpretation is in this case based on observations in the field, and it may be subject to revision when the rich material of fossils collected at different levels has been studied in greater detail. As mentioned in the description of the uppermost division of the "*Raniceps*" limestone the sediments in this part show, but for the colour, a great resemblance to the *Gigas* limestone. The most characteristic fossil of this division of the "*Raniceps*" limestone

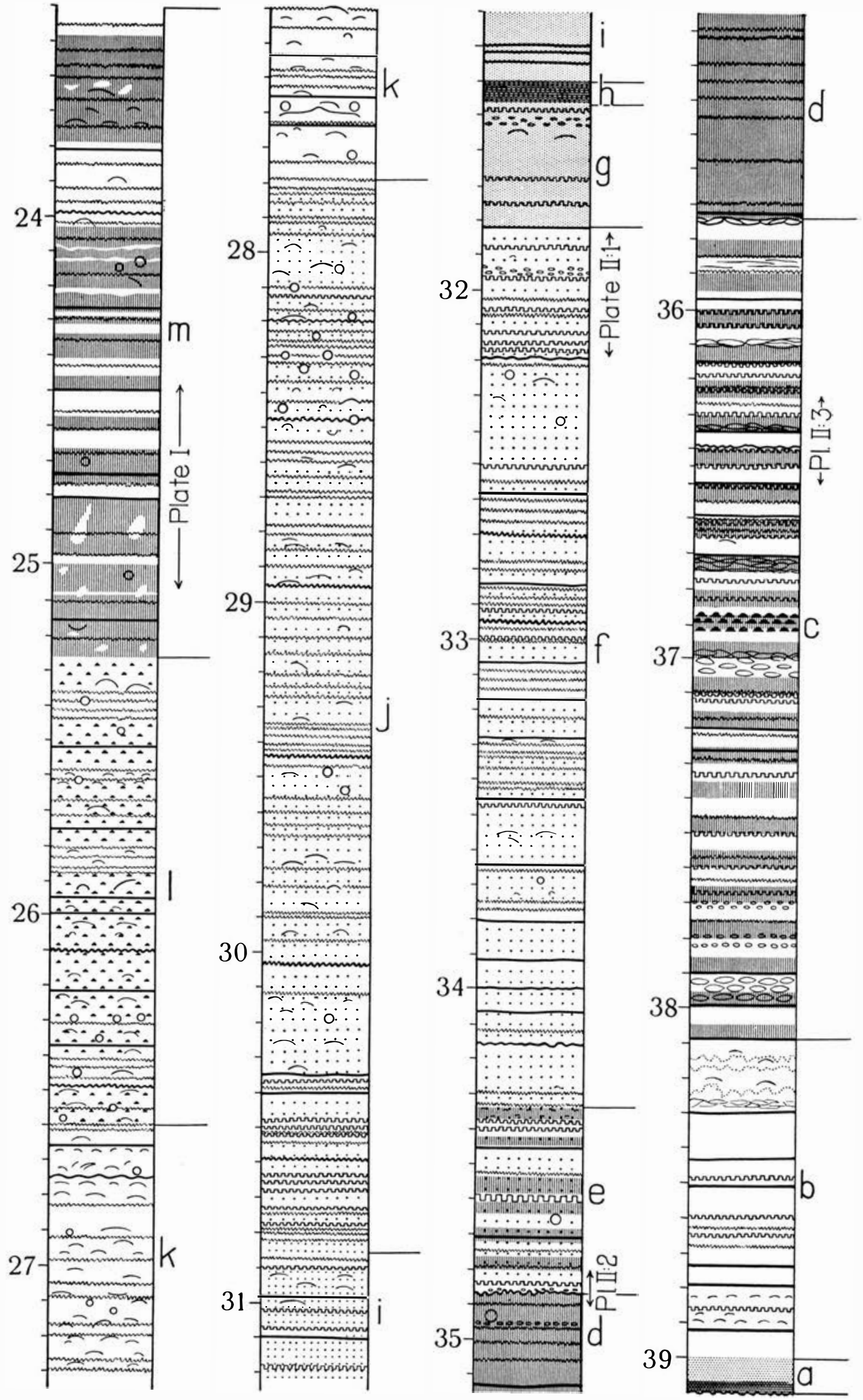


Fig. 2. Diagram of the Bödahamn core between 23.40 m and 39.15 m. Scale 1:200.

Red Limestone; Red Limestone with greyish green portions; Limestone with dark brown angular grains; Fine nodular limestone; Limestone fragments in matrix; Contact surfaces with rich marly intercalation; Fossils; Limestone with scattered grains of glauconite; ,, rich in glauconite; Glauconite sand; Limestone without coloured grains; Stylolite seam; Contact surfaces without marly intercalation; Irregular surface coated with glauconite

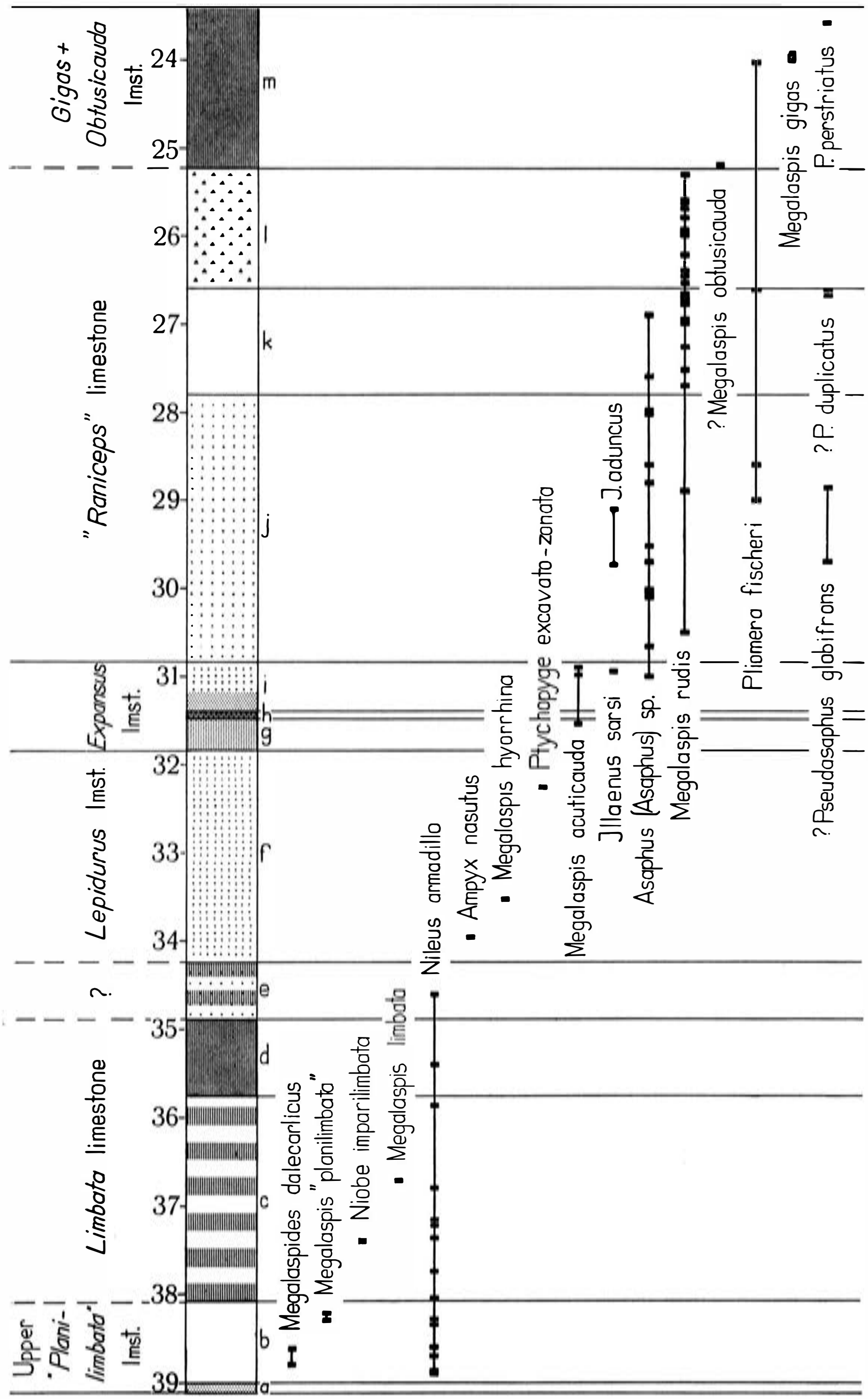


Fig. 3. The distribution of identifiable trilobite remains within the core. Designations in the columnar section same as in Fig. 2. (The variegation in the *Gigas* limestone omitted.)

seems to be *Pseudasaphus duplicatus* n. sp. (p. 141). Further, "*Isotelus*" *stacyi* has been found only in these beds. The first remains from Öland of this species were described from Gunnarslund (BOHLIN 1949, p. 546; Pl. I, Figs. 5 and 6). Later a cranidium and a pygidium were found in blocks of the Upper "*Raniceps*" limestone on the sides of the drainage ditch from the lake Marsjön, Föra.

Notes on Some Recent Field Work in Northern Öland

The *Gigas* and *Obtusicauda* limestones

In my 1949 paper the description of the above limestones was mainly based on finds from Gunnarslund and Marsjö, and at that time so little was known about the fauna, apart from a fairly abundant occurrence of *Megalaspis gigas*, that some fossils collected from a variegated limestone E. of Tokenäse hamn (l.c. p. 552) were erroneously interpreted as deriving from the "*Raniceps*" limestone. In 1949 northernmost Öland was again investigated, mainly to obtain more detailed evidence for the interpretation of the geological structure. The observations previously reported and those described below are plotted on the Map, Fig. 4.

ÖLANDS NORRA UDDE, (the Northern tongue of Öland; 1949 p. 539). —Grey limestone with a fauna typical of the "*Raniceps*" limestone has long been known from the northern side of the tongue ('11' on the Map, Fig. 4). Higher stages were not formerly described but were supposed to be present in a normal development (l.c.) In 1949 good exposures of *Platyurus* limestone were found along a power-line on the south-eastern side of the tongue The area in which the *Gigas* limestone very likely occurs, is mostly covered with a heavy deposit of shingle (cf. 1949, Fig. 4), but along a power-line branching off at '12' towards Björnnabben ('10') two pygidia of *M. gigas* and fragments of *Ampyx nasutus* were found in a block of a red and greenish grey, variegated limestone.

West of '14' grey limestone with darkbrown grains is exposed in the alvar surface. At '14' a thick bed of variegated limestone follows, forming a marked step. This must be the *Gigas*, or perhaps the *Obtusicauda* limestone (no fossils were collected). From the northernmost point of Öland and southwards the boundary between the "*Raniceps*" and the *Gigas* limestones probably runs in a fairly regular curve to opposite Byxelkrok, where the boundary is very irregular. The mapping was based on the colour of the limestone, but fossils collected at different points confirm the boundary thus obtained.

The localities '1'—'9' lie in the "*Raniceps*" limestone and of them '4'—'7' in layers with more or less glauconite. Outcrops of grey limestone without

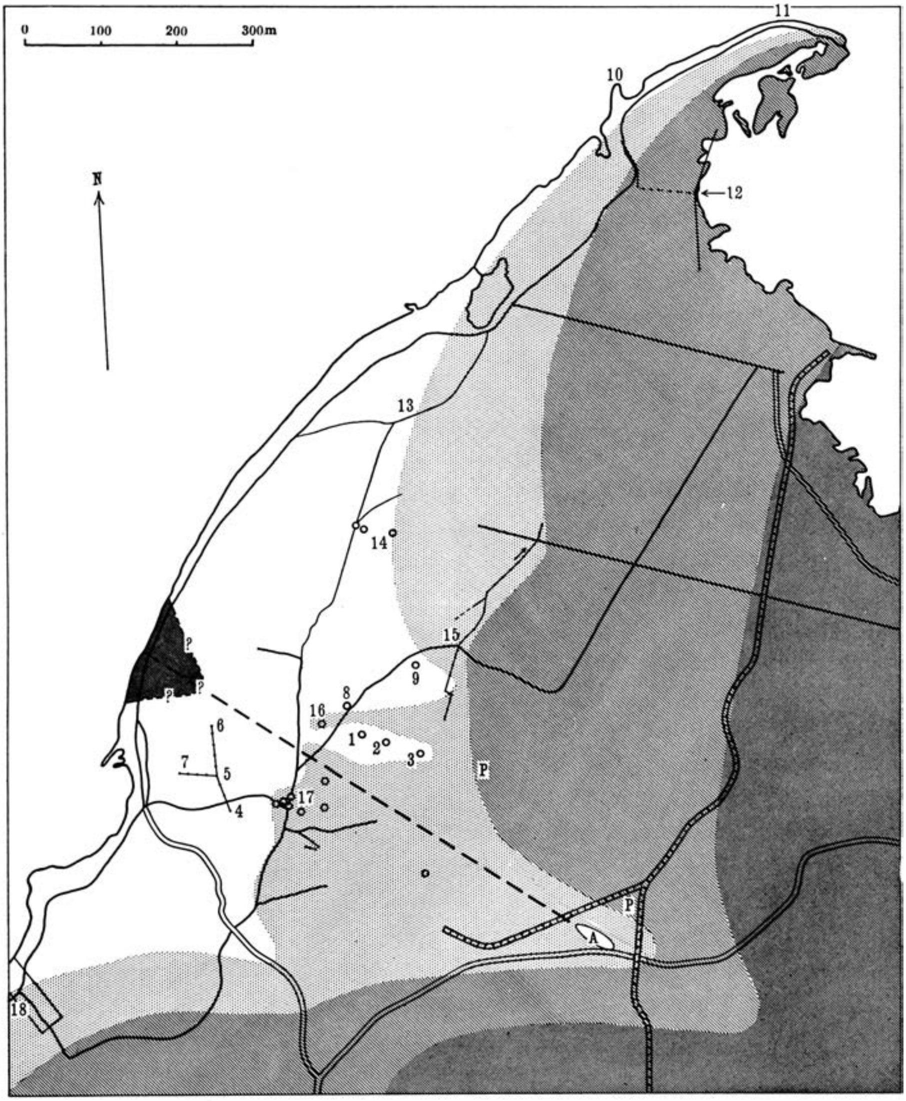


Fig. 4. Boundaries between some larger stratigraphical units in the Byxelkrok area. ▬ *Limbata* limestone. ▭ Grey beds (*Lepidurus* — Upper "*Raniceps*" beds [a small isolated occurrence of "*Raniceps*" limestone = *A*]). ▭ (?*Obtusicauda* and) *Gigas* limestone. ▨ *Platyurus* limestone (*P*). ▨ *Schroeteri* limestone. Numbered localities: See the text. Scale 1: 50.000

glauconite at '1' and '2' have yielded a rich "*Raniceps*" fauna; at '3', '8' and '9' the limestone is dark grey with brown specks, and contains remains of *Megalaspis rudis*.

The group of localities around '17' lies in red *Gigas* limestone, varie-

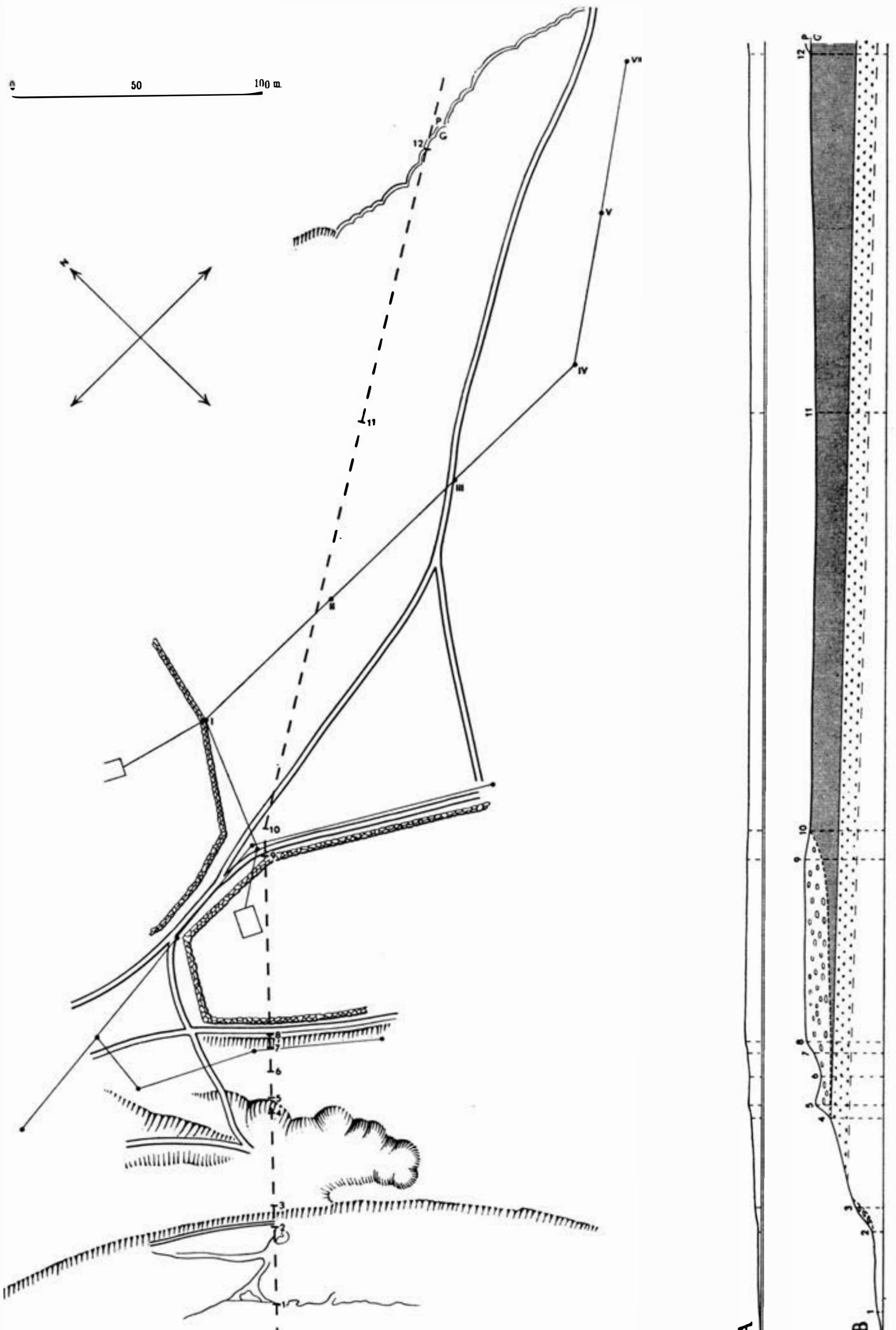


Fig. 5. Tokenäse Hamn and adjoining parts of the Enerum alvar. Detailed map and section at "18" in Fig. 4 by B. EKSTRÖM and S. KLING. Map: At *4*, a trench at the contact between Upper "*Raniceps*" and ?*Obtusicauda* limestones (see p. 127). Localities 1–4 in BOHLIN

gated with greenish grey; *M. gigas* was found in several places. Locality '16' also lies in red and grey limestone. In spite of the fact that the limit between the "*Raniceps*" and *Gigas* limestones is based on more observations than those plotted, the detailed course of the limit may possibly not be represented on the Map. A zone of slight folding is indicated by a broken line.

TOKENÄSE HAMN and the ENERUM ALVAR (around locality '18').—In 1949 (p. 552) a grey, brown-speckled limestone was mentioned from Tokenäse hamn. Later on a small trench was dug at the same place, and it turned out that red and grey, variegated limestone occurs at a much lower level than was previously suggested. The lowermost red bed is richly fossiliferous, but the fossils obtained are not very well preserved. It may belong to the *Obtusicauda* limestone. Fossils obtained:

Pterygometopus sp., *Celmus* aff. *granulatus* ANG., *Lichas coelorrhin* ANG., *Megalaspis* cf. *obtusicauda* n. sp., *Megalaspis* sp. (evidently identical with a small form common in the Upper "*Raniceps*" limestone at Föra), *Asaphus* sp. (possibly 2 species), *Pseudasaphus* sp., *Illaenus* sp., *Cyrtendoceras vaginatum* (SCHLOTH.).

At present the interpretation of this assemblage is difficult as very little is known about the fauna associated with *M. obtusicauda* in the parishes of Persnäs and Föra.

The new investigation shows, however, that the fossils mentioned from the Enerum alvar under 1—4 in BOHLIN 1949 (p. 552) definitely belong to the *Gigas* limestone. A revised faunal list, given below on p. 128, includes collections made in 1949 and 1953. It may be mentioned that it is no longer necessary to list the fossils from each locality separately, as it is now evident that the collections were made within the same part of the sequence and probably even within the same limestone bed.

"LÅNGALVARET".—An important locality ('15') with a rich *Gigas* fauna lies where the road from Byxelkrok to Nabbelund passes a large ditch.

Close to the northern side of the bridge the following section was measured, from the bottom of the ditch upwards:

1.	Variegated, red and grey limestone (fossils rare)	13 cm
2.	Red limestone rich in Orthoceracone cephalopods	11 ,,
3.	Variegated limestone (fossils few)	11 ,,
4.	Grey, fossiliferous limestone, in basal part red	9 ,,
5.	Oolithic, grey and pale brown limestone rich in fossils	20 ,,

1949, p. 552 are situated at *II—V* respectively on the map. *G—P*?, *Gigas—Platyurus* boundary (eastern limit of a superficial quarry in which evidently the *Platyurus* limestone was removed; *A. platyurus* occurs abundantly a little farther east). — *A* and *B*, Sections along — — — on the map. *P*, *Platyurus* limestone. *Gigas* + *Obtusicauda*, Upper and Middle "*Raniceps*" limestones designated as in Fig. 2 Between *2—3* and between *4—10*, the Ordovician beds are covered by shingle. Horizontal scale same as in the map. Vertical scale in *B* five times the horizontal.

Table I.

	B	L	E	H	G_1	G_2	S	F
Pterygometopus sp.	—	×	—	×	—	×	—	—
Cyrtometopus aff. *clavifrons* DALM.	—	×	—	×	—	×	×	—
"*Cheirurus*" sp. (Pl. III, Fig. 1)[1]	—	(×)	—	—	—	—	—	—
Celmus aff. *granulatus* ANG.	—	×	×	×	—	—	—	—
Pliomera fischeri (EICHW.)	×	×	×	—	—	—	—	—
Aristoharpes? rotundus n. sp.	—	—	—	×	×	—	—	—
Lichas coelorrhin ANG.	—	—	? ×	—	—	×	×	—
Megalaspis gigas ANG.	×	×	×	×	×	×	×	×
,, aff. *gigas* (Pl. III, Fig. 9)	—	×	—	—	—	—	—	—
,, sp. (Pl. III, Fig. 8)	—	—	—	—	—	×	—	—
Asaphus sp.	×	×	×	—	×	—	—	—
Pseudasaphus perstriatus n. sp.	×	×	×	×	×	×	×	×
Nileus armadillo DALM.	—	—	? ×[2]	—	—	—	—	—
Niobe frontalis DALM.	—	×	×	×	×	×	×	—
Illaenus glabriusculus JAANUSSON	—	×	×	? ×	×	×	—	×
Illaenus cf. *wahlenbergi* (EICHW.)	—	—	×	—	—	—	—	—
Ampyx nasutus DALM.	—	×	×	×	—	×	—	—
Orthambonites	—	× ×[3]	—	—	—	—	—	—
Estlandiid sp.	—	×	—	—	—	—	—	—
Cyrtendoceras vaginatum (SCHLOTH.)	×	×	×	×	—	—	—	×
Estonioceras sp.	—	×	×	—	×	—	—	—
Ortoceracone cephalopods	—	× ×[3]	× ×[3]	—	—	—	—	×
Ancistroceras sp.	—	×	—	×	—	×	—	—
Echinoencrinites sp.	—	—	—	—	—	—	—	×

1, 2, and 3 represent the typical development of the *Gigas* limestone in Öland. Most of the fossils listed above come from layer 5 and the upper, grey part of layer 4.

The list above includes fossils from the boring at Böda hamn (B), loc. 15 see Text Fig. 4) at the northern end of Långalvaret (L), the alvar at Enerum (E), a locality near Bäckalund, N. of Hornsjön (H), two quarries at Gunnarslund, Persnäs, one at the railway station (G_1), the other 1 km SW. of the station (G_2), Södvik, Persnäs, where a drainage ditch is crossed by a road 500 m E. of the main road (S), and, finally, the drainage ditch E. of the railway station at Föra (F).

As indicated by the list of fossils, *Megalaspis gigas* is undoubtedly the most common and characteristic fossil in the beds treated. *Pseudasaphus perstriatus* and *Niobe frontalis* are also restricted to these beds, however. They might therefore be almost as important as index fossils as *M. gigas*, but they seem to occur in greater abundance only in a certain facies of the *Gigas* limestone. The richly fossiliferous limestone described above is at present known only from Northern Öland. It is best available at localities

[1] From a point about 1 km N. of the main locality in the same ditch.

[2] Mentioned from this locality in 1949, but no specimen referable to the species could be found when the collection was reexamined.

[3] × × = 2 species.

situated within the Western part of the parish of Böda. The boring at Böda hamn evidently passed through the easterly continuation of this limestone.

A small collection of fossils made at Wedby in the parish of Högsrum includes *Pseudasaphus perstriatus*, together with the following association: *Celmus* aff. *granulatus*, *Ceraurus* sp., *Remopleurides* sp., *Megalaspis* cf. *heros*. In Northern Öland *P. perstriatus* was constantly found together with *Megalaspis gigas;* of the other fossils *M. heros* has not yet been found at so high a stratigraphical level in the northern part of the island.

Description of the Fossils

? Aristoharpes WHITTINGTON 1950

Aristoharpes? rotundus n. sp. — Pl. III, Figs. 5—7.

Holotype. The cephalon, U.M No. Ar. 4225.

Locus typicus. Öland, Parish of Persnäs, Gunnarslund.

Stratum typicum. Upper "*Raniceps*" limestone.

Derivatio nominis. The specific name alludes to the almost perfect circle described by the outline of the cephalon.

Diagnosis. Most characters of *Aristoharpes* (WHITTINGTON 1950, p. 11). Outline of cephalon circular. Prolongations shorter than axial length of cephalon.

Material. A small almost complete cephalon (Holotype) from the Upper "*Raniceps*" limestone, and two fragmentary ones (one of them an internal mould) from the *Gigas* limestone.

Description.[1] Cephalon moderately convex, outline circular, maximum width a little in front of occipital ring. Prolongations somewhat more than $^2/_3$ of the axial length of cephalon curving slightly inwards towards the acute tips. Width of glabella about $^1/_7$ the width of cephalon, its length half the axial length. Glabella narrow with parallel sides, rounded anteriorly, its base sunk between the cheek lobes but middle part rising high above these. Basal glabellar lobes not well preserved, small, evidently limited to posterior $^1/_3$ of glabella. Occipital furrow and occipital ring not preserved. Preglabellar field short, sloping rather steeply forwards, laterally passing into cheek lobes. These slope steeply towards dorsal furrows and very steeply outwards. Eyes small, situated slightly behind anterior end of glabella. Eye ridges faint, transverse, reaching dorsal furrows a little behind the anterior end of glabella. Alae small, subcircular, flattened. Posterior marginal furrows deep; posterior margin bent upwards, continuous with the upper internal rim.

[1] The terminology in the description is that used by WHITTINGTON.

Cheek roll very little convex, steeply inclined in the direction of the brim, and demarcated upwards by a very faint furrow. Cheek roll prolongations short. Brim flat, or even slightly concave on the upper surface, sloping gently outwards, somewhat more so anteriorly than on the brim prolongations, $1\frac{1}{2}$ times as wide anteriorly as width of glabella across basal lobes. The upper and lower external rims are evidently equally developed. Girder partly indistinct, evidently bending inwards behind the cheek lobes, not reaching the tips of prolongations. Marginal band not available for observation. Structure on brim, cheek rolls, and prolongations a fine dense pitting indistinctly arranged in radiating rows.

Hypostome, thorax and pygidium unknown.

Remarks. Of the genera erected by WHITTINGTON (1950) only *Aristoharpes* can receive the new species from Öland. This does, however, not necessarily mean that *A. rotundus* will definitely remain in that genus. The age of the British specimens is Lower Silurian (Middle and Upper Llandovery), whereas the new species comes from the upper part of the Lower Ordovician (Upper Arenig). It is true that in *Aristoharpes* the outline of the cephalon is oval and not circular, but the rim runs in even bows from the anterior part on to the prolongations. These latter are pointed. Other common features are the narrow glabella, the small alae, the position of the eyes, and the surface structure of the test.

Of WHITTINGTON's other genera *Selenoharpes* also has the incurved pointed prolongations. It has, however, a much broader glabella and larger alae; the eyes lie farther backwards and the eye ridges are distinct. The structure on the cheek lobes consists of terrace lines and, between them, small pits, hence another structure than that in the form from Öland. *H. concavus* THORSLUND (1940, p. 152) is referred to *Selenoharpes* by WHITTINGTON; this form too differs from *A. rotundus* in the characters enumerated above.

Paraharpes has a broad glabella, larger alae, and, furthermore, the girder extends to the tip of the prolongation. The broad glabella is present also in *Platyharpes, Dolichoharpes* and *Eoharpes*.

None of the forms described from Sweden and its neighbouring countries can be identical with *A. rotundus*.

The oldest one—"*Harpes*" *excavatus* LINNARSSON 1875—differs e.g. in the structure on the brim (terrace lines and pits). In *H. scanicus* the glabella is somewhat broader but otherwise similar, the whole cephalon must, however, have been oval (narrower and more elongate than in *A. rotundus*).

The Silurian forms also differ in characters of the glabella, shape of cephalon etc., and their age makes it highly improbable that they should be identical with *A. rotundus*.

Occurrence. Gunnarslund, Persnäs. Two of the specimens mentioned above; these come from different levels, the holotype from the Upper "*Raniceps*" limestone, the other one from the *Gigas* limestone.

Bäckalund, Högby (*Gigas* limestone).

The specimens from the *Gigas* limestone are poorly preserved, but they have the flat brim and the circular outline in common with the holotype.

Megalaspis ANGELIN 1851

Megalaspis obtusicauda n. sp. — Pl. IV, Figs. 1 and 2; Text Figs. 6A—D, and 7A.

1949 *Megalaspis centaurus* DALMAN, BOHLIN, Pl. I, Fig. 1.

Holotype. The pygidium, Pl. IV, Figs. 1 and 2; Text Figs. 6 A, C and 7 A. U.M. No. Ar. 4216.

Locus typicus. Öland, parish of Persnäs. Gunnarslund.

Stratum typicum. *Obtusicauda* limestone.

Derivatio nominis. The specific name alludes to the broadly rounded posterior end of the pygidium.

Diagnosis. Cranidium with a swelling in front of glabella. Pygidium elongate, width/length index in holotype 0.88, parabolic with broadly rounded posterior end. Rhachis in anterior half slightly convex and delimited from side lobes by shallow grooves, in posterior half flat and almost flush with the sides. Ribs double, 7 or 8 anterior ones better marked than those behind. Surface structures in posterior half faint and hardly visible except in strongly oblique light.

Material. Two fragmentary, poorly preserved cranidia, a great number of pygidia.

Description. See diagnosis. The width/length index varies between 0.84 and 0.88; Fig. 7 A, in which the outlines of the best preserved pygidia are drawn, gives a general idea of the shape of the pygidium (about the exceptionally long specimen with an index of about 0.78, see below). The measurements were mostly taken on reconstructions of the outline, and as the index is considerably influenced by slight differences in width or length, the index values give no more than an approximate idea of the proportions of the pygidia. The structure of the inner surface of the shell which is in all specimens preserved as impressions on the internal mould is very constant. Where the shell is partly preserved its outer surface has been dissolved, evidently by sea water immediately after deposition, and nothing can be said about the relief of this surface of the shell.

In the holotype the rhachis has *c.* 24 rings, the anterior ones more strongly marked, occupying half of the length (details not from type). There are 16 or 17 ribs. One of the pygidia from Föra is exceptionally long (1949, Pl. I, Fig. 1). On the rhachis 27 rings can be counted and on the sides 19 ribs. Further the upper surface is strongly flattened, whereas in all other specimens it is evenly vaulted (Text Fig. 6 B and D). This specimen

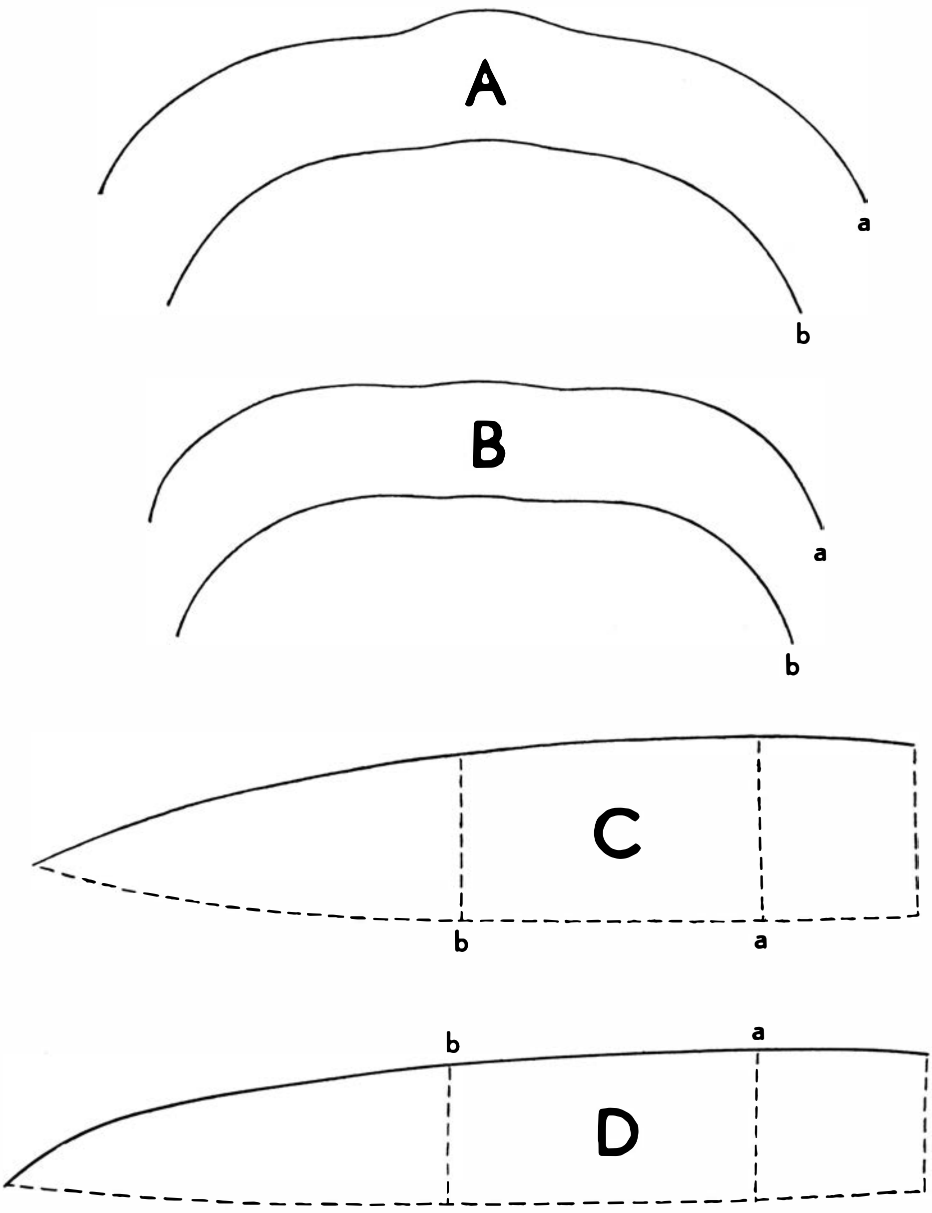
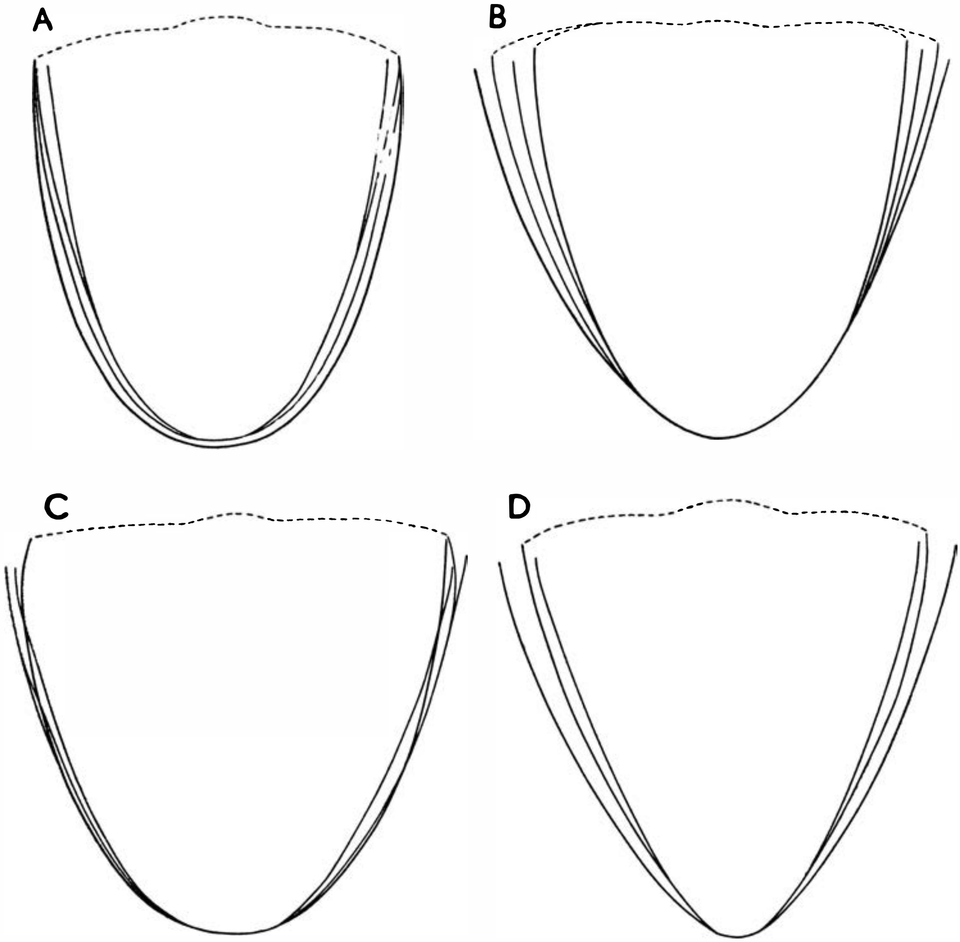


Fig. 6. *Megalaspis obtusicauda* n. sp. Transverse and sagittal sections of pygidium. *A* and *C*, Holotype Pl. IV, Figs. 1 and 2; *B* and *D*, Specimen in BOHLIN 1949, Pl. 1, Fig. 1. In the cross-sections missing parts on either side are restored. Nat. size.

is in many respects better preserved than any of the others, and therefore it was chosen in 1949 to represent the species; it is provisionally considered to be an aberrant specimen of *M. obtusicauda*.

Remarks. *M. obtusicauda* is a new name for a species that has long been



Fig, 7. Groups of outlines of pygidia. Size of specimens in the drawings "standardized" to facilitate the comparison. *A*, *Megalaspis obtusicauda;* *B*, *Megalaspis gigas;* *C*, *Megalaspis rudis;* *D*, *Megalaspis* sp. Lenstad (cf. BOHLIN 1949, Pl. 1). All approximately × ½.

known but never properly described. The only earlier specimen in the Uppsala museum was collected by WIMAN in 1902 at Byerum in a drainage ditch, where the species was said by WIMAN to occur in very great abundance. The only preserved specimen was, however, by WIMAN labelled *M. gigas*, but in his diary "*M. centaurus*" is mentioned from the same locality, and this name undoubtedly was meant to designate the present species.

The specific name of *centaurus* cannot be used. It was proposed by DALMAN for "die auf Oeland vorkommenden grossen Hörner des Kopfes irgend eines unbekannten Paläaden" (1827, German Ed. 1828, p. 59). There is no figure, and more than one of the large *Megalaspis* spp. may claim the right to the name. Especially noteworthy are the specimens in HISINGER's collection deriving from Ormöga in Alböke, a locality mentioned also by

DALMAN, where only very low levels of the "*Raniceps*" limestone are exposed (cf. HOLM 1883, p. 91). The specimens from the MARKLIN collection mentioned by HOLM (l.c. p. 90) and also by DALMAN (l.c.) are from different levels of the "*Raniceps*" limestone, in one case with glauconite, in most cases without any macroscopical grains, and finally in one case with the dark brown grains characteristic of the upper division of the "*Raniceps*" limestone.

Most of these free cheeks probably belong to *M. rudis* which has not till now been found in the red beds immediately underlying the *Gigas* limestone. There is, however, another question to be considered, as Dr JAANUSSON has pointed out to me. DALMAN in his paper (l.c. p. 58 & 59) described a number of incompletely known forms, "nur um die Sammler darauf aufmerksam zu machen, und sonach vielleicht Anleitung zur frühern Entdekkung derselben zu geben", and the names given "sind nur die provisorischen, welche den hier beschriebenen, im Museum der Königl. Akademie der Wissenschaften aufbewahrten Fragmenten beigelegt wurden". Thus it is evident that DALMAN did not intend to describe the material as a new species, and *Asaphus centaurus* may therefore be declared a *nomen nudum*.

SCHMIDT has adopted *M. centaurus* for a species from the East Baltic area, which according to him is identical with the form mentioned by DALMAN under this name. He gives a long list of synonymes, including *M. grandis* SARS, *Asaphus longicauda* v. LEUCHTENBERG, *M. multiradiata* ANGELIN, *M. latilimbata* ANGELIN?, *M. rudis* ANGELIN.

The Norwegian *M. grandis* might be identical with *M. rudis* (see p. 137), at least it is not identical with *M. obtusicauda* from Öland.

The type specimen of *Asaphus longicauda* was found in a region where specimens described by SCHMIDT as *M. centaurus* occur. SCHMIDT has undoubtedly seen v. LEUCHTENBERG's specimens and his identification of them with his *M. centaurus* must be correct.

M. multiradiata was described by ANGELIN from Ljung in Östergötland. Some pygidia from the type locality are labelled by ANGELIN. They occur in a lenticular limestone with abundant marly intercalations. They are badly preserved, somewhat deformed, and their surface structures partly effaced by slides within the rock. The shape of the pygidia as well as the development of the rhachis and the ribs, as far as these are preserved, reminds one of *M. gigas*, but as full certainty on this point cannot be obtained, *M. multiradiata* must be considered a *nomen dubium*.

M. latilimbata was found at Sandvik in Öland, where the "*Raniceps*" limestone and still lower beds are exposed. The type is lost, and as ANGELIN's description and figure leave one in doubt as to the characters of the species, this name too is a *nomen dubium*.

There is finally *Megalaspis rudis*, described by SCHMIDT as a subspecies of *M. centaurus*. The pygidium, l.c. Text Fig. 32, is very similar to the pygidium of what is considered to be *M. rudis* in Öland (BOHLIN 1949, Pl. I, Fig. 2) and the species is certainly not identical with *M. obtusicauda*.

Some of the names enumerated by SCHMIDT thus seem to be synonymes of his *M. centaurus*, others are doubtful. About the relation of SCHMIDT's *M. centaurus* to *M. obtusicauda* see p.

Occurence. Enerum?, Byerum (parish of Böda), Horn (parish of Högby), Gunnarslund (parish of Persnäs), Wässby (at the large drainage ditch from the lake Marsjön in the parish of Föra).

Megalaspis gigas ANG. — Pl. IV, Figs. 3 and 4;
Text Fig. 7 B.

Lectotype. The pygidium, Pl. V, Fig. 3. Riksmus. Stockholm, Nr. Ar. 21 770.

Locus typicus. Öland, Parish of Hulterstad.

Stratum typicum. *Gigas* limestone.

Derivatio nominis. The specific name evidently alludes to the large size of the species.

Diagnosis. Cranidium with a large swelling in front of the glabella, rostrum long. Pygidium subtriangular with strong pleural ribs divided only at their distal ends. Rings on rhachis much more pronounced on the sides than in the middle.

Remarks. What we have identified as *M. gigas* in Öland certainly belongs to this species. The species was first described from Öland (ANGELIN 1878, p. 16); Segerstad, situated on the eastern side of the island, is mentioned by ANGELIN, which shows that the species comes from a high level; and, last but not least, ANGELIN's figure (Pl. XII, Fig. 3) agrees in every detail with the diagnosis given above.

The specimens figured by ANGELIN cannot be identified among the pygidia collected by him in Öland. There is, however, in his collection a fairly good pygidium from Hulterstad, the parish north of Segerstad (ANGELIN p. 16: "Oelandiae e. gr. ad Segerstad etc."). It may be of some interest to mention that there is a label glued to the back of this specimen with "*Asaphus Longicauda*? Leuchtb.", in ANGELIN's handwriting.

The cranidia found in the beds where pygidia abound show a strong swelling on the preglabellar field, immediately in front of the glabella. Such a swelling evidently occurs in other species, but if it is not present the cranidium cannot belong to *M. gigas* (see below). There is, however, a great variation within the material of cranidia found in the *Gigas* limestone. Those in Pl. III, Figs. 8 and 9, are so different that they seem to belong to different species; both differ from larger specimens from Dalarna and Öland and these latter are, in their turn, not quite alike. Until a revision of the Swedish species of *Megalaspis* will have been made, it is useless to enter upon a more detailed description.

Megalaspis gigas was mentioned by BRÖGGER (1882, p. 82; cf. also STØRMER 1953, p. 117) from the uppermost beds of the *Endoceras* limestone (3 *cγ*) in the Oslo area. Specimens from Norway were sent to Uppsala for comparison and have been studied by Dr. JAANUSSON and myself.

In his paper STØRMER has distinguished the *Gigas* limestone in Norway. It is evident from the discussion below that the Norwegian material of fossils on which this conclusion is based is in need of a revision.

Most of the Norwegian material was found in shales and was subject to deformation after imbedding. In some cases this makes the comparison with Swedish specimens found in limestones somewhat difficult, but as far as can be judged from the better preserved specimens, *M. gigas* is not present in the material. The specimens labelled *M. gigas* may belong to two (or three?) species, none of these with certainty referable to Swedish forms:

One of the species is represented by undeformed limestone specimens and differs from *M. gigas* in the following characters: The rhachis is narrow, the rings uniformly developed across the rhachis, ribs comparatively long. The rhachis is depressed in relation to the pleurae so that a plane placed on the pygidium rests on the latter; in *M. gigas* the rhachis is raised above the sides. A fragmentary cranidium associated with the best preserved pygidia, and probably belonging to the same species as these, shows only a slight elevation in front of the glabella, and the glabella itself differs considerably from specimens from Öland and Dalarna.

What is possibly another species is represented by a single fragmentary pygidium (Oslo Museum 2670). The rhachis is more elevated than in the other specimens; it is apparently relatively as broad as in *M. gigas*, but it is more convex than in this species and the rings run with uniform development from side to side.

FR. SCHMIDT (1906, Pl. VIII, Fig. 5) figures a pygidium under the name of *M. centaurus*. This differs from the pygidia in the *Obtusicauda* limestone in having a much more pronounced rhachis and more pronounced ribs, whereas in the Öland form rhachis and ribs on the posterior half of the pygidium stand out only in very oblique light. SCHMIDT's specimen is therefore more likely identical with or very closely related to *M. gigas*, a species which was thought to be absent from the East Baltic deposits.

M. longicauda LEUCHTENB. is considered by SCHMIDT to be identical with his *M. centaurus*. As this latter name is obviously a *nomen nudum*, the correct name for the East Baltic species should be *M. longicauda*. The question of a possible identity of *M. longicauda* with *M. gigas* must be left unanswered until the type specimens can be compared. To judge from SCHMIDT's figures *M. longicauda* agrees with *M. gigas* in the shape of its pygidium and in having distinct ribs also posteriorly. It differs in having divided ribs (best seen in Text Fig 31, l.c.). In *M. gigas* the ribs are double only at their distal ends; only in one single small pygidium from Enerum (Pl. IV, Fig. 4) the anterior ribs are slightly flattened and faintly grooved almost from the rhachis. An identity with *M. gigas* has been suggested by ANGELIN (see above) and BRØGGER (SCHMIDT l.c. pp. 57 and 59). Against BRØGGER, SCHMIDT has remarked that the ribs are more distinct on the internal mould than on the shell, which, however, seems to be the case also in *M. gigas*.

Megalaspis grandis SARS

1835 *Asaphus grandis* SARS
1882 *Megalaspis grandis* BRÖGGER
1906 „ *centaurus* SCHMIDT
1953 „ *grandis* STØRMER

The pygidium of this species is shorter than those referred to *M. obtusicauda*. It agrees much better with pygidia from Öland, designated as *Megalaspis rudis*. The cranidia in the material are, however, all of them different from *M. rudis* from Öland and from *M. gigas* and *M. obtusicauda* as well, the preglabellar field being broader, shorter and more abruptly constricted to a point. There is no swelling in front of the glabella.

At the same level as this "*rudis*"-like pygidia a small cranidium (O. M. 33199) was found which is identical in structure with two small cranidia from the Upper "*Raniceps*" limestone in Öland, evidently belonging to *M. heros*.

Summary remarks on Megalaspis

1. For *M. gigas* a lectotype, Riksmuseum Stockholm Nr. Ar. 21770, collected by ANGELIN in the parish of Hulterstad Öland, is chosen.

2. *Megalaspis gigas* is till now not found in Norway; the specimens mentioned under this name very likely belong to other species.

3. The name *M. centaurus* is evidently a *nomen nudum*. SCHMIDT's material described under this name seems to be referable to *M. longicauda* v. LEUCHTENBERG. It shows great resemblance to *M. gigas* but differs in having divided ribs.

4. For the form from Öland which in 1949 was called *M. centaurus*, a new species *M. obtusicauda* is created. This species is at present known only from Öland.

5. *M. grandis* SARS may be different from anything yet recognized from Sweden.

6. *M. multiradiata* ANGELIN is based on badly preserved material that might belong to *M. gigas*. The name is considered a *nomen dubium*, as is also the name *M. latilimbata*.

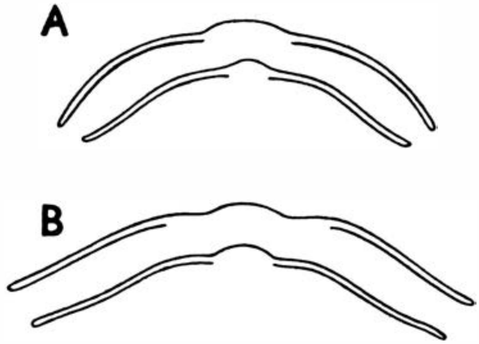


Fig. 8. Cross-sections of pygidia of *A, Pseudasaphus duplicatus* (at the arrows in Pl. V, Fig. 2); *B, Pseudasaphus perstriatus* (at the arrows in Pl. V, Fig. 3). Missing parts on either side restored. Nat. size.

Asaphus BRONGNIART 1817

Asaphus (Neoasaphus) sulevi cf. **knyrkoi** FR. SCHM. — Pl. IV, Fig. 5.

A small cranidium, U. M. Nr. Ar. 4226, from the *Obtusicauda* limestone E. of Lake Marsjön, Föra (1949 p. 548) was determined by Dr. JAANUSSON as probably belonging to this species. Some asaphid pygidia from the *Gigas* limestone might belong to the same species, as a specimen from Enerum very closely resembles SCHMIDT's Text Fig. 31 (1901).

Pseudasaphus FR. SCHMIDT 1901

Pseudasaphus perstriatus nov. sp. — Pl. V, Figs. 3–5; Pl. VI, Figs. 1 and 2; Text Fig. 8 B

Holotype. A pygidium Pl. V, Fig. 3; Text Fig. 8 B. U. M. Nr. Ar. 4240.

Locus typicus. Öland, parish of Böda. Type specimen from the boring at Böda hamn.

Stratum typicum. *Gigas* limestone.

Derivatio nominis. From the fine and very dense terrace lines on the doublure.

Diagnosis. Pygidium subtriangular, broad, its length a little more than $^2/_3$ of its width, comparatively little elevated, with a broad limb. Doublure reaching posterior $^1/_3$ of rhachis. More than 40 terrace lines on the broadest part of the doublure (see p. 140). Terrace lines on the upper surface of the test reaching the border.

Material. 8 fragmentary cranidia, about 15 pygidia (some of them very fragmentary).

Description (based on the figured specimens).

Preglabellar field well developed and flat, widening opposite greatest width of glabella, protruding anteriorly into a median point. At a point $^2/_5$ of length of cranidium from the front, the fixed cheek rises slightly backwards from a transverse line (position of anterior pit of dorsal furrow?; see below) to form a longitudinal ridge reaching the incision in front of palpebral lobe.

Frontal lobe of glabella sharply demarcated, with a faint median ridge entering preglabellar field in a point; its greatest width approximately $^2/_3$ of width across preglabellar field. Glabella in front of eyes moderately convex. Behind the frontal lobe a large anterior and a quite small middle pair of glabellar lobes can be distinguished. From the posterior widening of the glabella a faint basal lobe, demarcated by flat ridges, extends on each side, the ridges diverging towards base of palpebral lobes; anterior ridges curving first forwards then outwards ending in a point opposite the middle of these lobes, posterior ridges ending in the incision behind the lobes. Occipital ring flat, flush with posterior part of glabella. Glabellar tubercle small, situated halfway between eyes and posterior border.

Preglabellar furrow faint around the middle protrusion of glabella, otherwise marked and continuous with the equally developed anterior part of the dorsal furrow. Anterior pit of the dorsal furrow indistinct (see above). Posterior part of the dorsal furrow faint, passing closely inside the base of the palpebral lobes. Basal glabellar furrow well developed reaching opposite posterior $^1/_3$ of palpebral lobes. Occipital furrow distinct only on the sides (to halfway between middle line and occipital part of dorsal furrow). Faint transverse groove in the middle of the occipital ring. Occipital part of dorsal furrow deep extending only halfway from posterior border to the eyes. Posterior marginal furrow evidently parallel to posterior border of cephalon, deep medially (running between marked swellings), becoming shallower laterally.

Faint terrace lines present on the sides of the frontal lobe running approximately parallel with the preglabellar furrow, stronger ones on the palpebral lobes and on the ridges bordering the posterior marginal furrow. In other parts of the cranidium no terrace lines can be seen.

Nothing of the thorax is preserved.

Pygidium subtriangular, moderately convex in the middle, concave on the sides and behind, so that a rather broad limb is formed. Length of pygidium a little more than $^2/_3$ of its width. Rhachis comparatively strongly convex, with 13–14 rings, best seen where the test is removed, the 7 anterior ones very distinct. The sides of the pygidium carry a number flat ribs, one or two pairs in front very distinct; in the figured specimens the first rib seems to be very much more marked than the ribs behind it, and this might be the rule; on the doublure (Pl. V, Fig. 5) 10 ridges can be counted lying opposite 7 rhachis rings. These ridges do evidently not each correspond to a rib.

Pygidial facets only slightly deflected downwards, occupying each somewhat less than $^1/_4$ of the width of the pygidium; antero-lateral corner broadly rounded. Ridge forming anterior border of pygidium strongly developed medially (to about $^2/_3$ of the width from the rhachis), then passing into blunt edges delimiting the facets posteriorly.

Doublure broad, reaching posterior $^1/_3$ of rhachis, in front its inner border diverges from rhachis at a very acute angle (cf. JAANUSSON 1953, Fig. 5: 3).

Terrace lines on doublure of the type specimen 14—>22 per 5 mm (varying according to where they are counted). Terrace lines on upper surface of test reaching the border.

Remarks. The material was first thought to belong to *Pseudasaphus globifrons* EICHW. which seems to be a rather variable species (cf. for instance the glabellae in SCHMIDT 1904, Taf. I). But the terrace lines on the doublure of the free cheeks as well as of the pygidium are in all specimens few and comparatively widely spaced, viz. 6—8 to 5 mm and about 20 in the whole width of the doublure of the pygidium, thus only half, or even less than half as many as in *P. perstriatus*.

The only genus among those described by SCHMIDT, where the dense striation of the doublure is met with, is *Ptychopyge*. Most of the species of this genus have a characteristic convex limb, e. g. *P. angustifrons*; only in one species, *P. pahleni*, the pygidium is uniformely vaulted. The pygidium seems, however, to be more elevated than in *Pseudasaphus perstriatus*, and if there is a limb at all, it must be much less pronounced than in this species. *Ptychopyge pahleni* also has the small tubercle behind the eye, characteristic of the genus *Ptychopyge*, and such a tubercle is not present in *Pseudasaphus perstriatus*.

According to SCHMIDT (1904, p. 49) *Ptychopyge pahleni* might be identical with *P. limbata* ANG. This is a form from Öland. The specific name, *limbata*, indicates the presence of a limb as in *Pseudasaphus perstriatus*, and the "Regio C" of ANGELIN's also comprises the *Gigas* limestone. But in the Upper "*Raniceps*" limestone which also belongs to "Regio C" another species with densely striated doublure and a distinct though narrower concave limb occurs (see p. 141). The type of *Ptychopyge limbata* was lost (SCHMIDT l.c., p. 49); ANGELIN's figure is probably not exact enough for an identification of new material and his description is too brief to comprise all essential details; therefore ANGELIN's species had perhaps better be neglected.

For a comparison with *P. duplicatus* from the Upper "*Raniceps*" limestone, see p. 142.

Occurrence. *Pseudasaphus perstriatus* is at present with certainty (cf. p. 129) known only from the *Gigas* limestone where it seems to be a very common element in the richly fossiliferous facies recently discovered in Öland.

Öland. See p. 128. The species was also found at the following localities: Böda: On the alvar a couple of hundred metres S. of the bridge across the small brook at Byerum. Högby: On the alvar between lake Hornsjön and Alvidsjö bodar. Högsrum: At the cross-road W. of Wedby.

Dalarna. Rättvik: Vikarbyn.

Pseudasaphus duplicatus nov. sp. — Pl. V, Figs. 2 and 7; Pl. VI, Figs. 3 and 4; Text Fig. 8 A.

Holotype. A pygidium Pl. V, Fig. 2; Text Fig. 8 A. U. M. Nr. Ar. 4239.

Locus typicus. Öland, parish of Persnäs, Gunnarslund.

Stratum typicum. Upper "*Raniceps*"-limestone.

Derivatio nominis. From the very broad doublure that approaches the rhachis also anteriorly.

Diagnosis. Pygidium broadly rounded, its length $^2/_3$ of its width, moderately elevated, slightly concave along a narrow zone along its borders. Doublure reaching the posterior $^2/_3$ of the rhachis. More than 60 terrace lines in the broadest part of the doublure. Terrace lines on the upper surface of the test very scarce or absent along the free borders of the pygidium.

Material. A fragmentary free cheek, three cranidia, a great number of pygidia, most of the material lacking the test.

Description. Cephalon evidently rather strongly convex; its outline unknown. Postero-lateral corners evidently forming acute angles with rounded points. No genal spines.

Preglabellar field well developed and flat, with a great antero-posterior extension in the middle, where it protrudes in a point, and widening also a little in front of greatest width of glabella. Behind a line through the foremost point on the glabella the upper surface of the fixed cheeks is occupied by a longitudinal swelling, broad and indistinct in front, narrowing to a marked ridge when approaching the eye, the transition between the different structures being gradual, without the break noticed in the type specimen of *P. perstriatus* (the only one in which this detail is preserved, see p. 139).

Frontal lobe somewhat diffusely demarcated in front, where a short ridge from the preglabellar field extends into it, ending backwards in a point. Greatest width of glabella $^2/_3$ of width across preglabellar field. Glabella in front of eyes moderately convex. A faint median ridge on the glabella extends backwards to opposite the notches in front of the palpebral lobes. On posterior part of glabella three pairs of faint ridges diverging forwards at obtuse angles, the anterior pair evidently marking the backward extension of the frontal lobe. Anterior glabellar furrow wide, almost as wide as the distance from its posterior border to the basal glabellar furrow. The latter distance is divided in two equal parts by the middle glabellar furrow. Basal lobes triangular. Between the basal lobes there is moderate swelling carrying the glabellar tubercle near its posterior side. Occipital ring only slightly convex.

Preglabellar furrow and its continuation backwards somewhat diffuse, equally developed around the frontal lobe. Shallow, indistinctly demarcated anterior pit very near the notch in front of eye lobes. Anterior, middle and basal glabellar furrows distinguishable (see above). Dorsal furrow at basal lobe faint, ending a little medially to anterior end of occipital portion of the same furrow, joining it at an angle. Laterally to it a longitudinal elevation extending from the base of palpebral lobes to posterior marginal furrow. Occipital furrow broad and shallow, best marked on the sides. Posterior marginal furrow deep and well marked in its medial portion where it is "pinched" by a high narrow ridge bending slightly backwards behind the eye, widening laterally and diverging slightly from posterior border.

No terrace lines present on preserved cranidial portions of test. (cf. Pl. VI, Fig. 3).

The free cheek, Pl. V, Fig. 7, is very defective. There was no spines at the postero-lateral corners. The specimen also shows the extension or the doublure, the Panderian organ, the course of the postorbital suture and and the size of the eye.

Nothing of the thorax is preserved.

Pygidium broadly rounded, convex with a shallow, narrow concavity along its borders. Length $^2/_3$ of width. Rhachis comparatively strongly convex with 13 rings, the 6 anterior ones very distinct. 7 very faint ribs distinguishable on the sides of the pygidium reaching about halfway from rhachis to the border, more distinctly seen on doublure as flat areas separated by shallow grooves, each area divided by a more or less pronounced furrow (in the type specimen only 4 such areas are well marked).

Pygidial facets large, each occupying about $^1/_3$ of the width of the pygidium. Facing obliquely forwards. Antero-lateral corner broadly rounded. Ridges anteriorly on the pygidium pronounced, sharply marked also on the sides behind the lateral portions of the pygidial facets.

Doublure very broad, reaching posterior $^2/_3$ of rhachis and closely approaching anterior $^1/_3$.

The terrace lines on the doublure are about 18 to each 5 mm. Terrace lines on the upper surface of the test do not reach the border in the posterior $^2/_3$ of the pygidium.

Remarks. *Pseudasaphus duplicatus* nov. sp. should first of all be compared with *P. perstriatus* from the *Gigas* limestone. The glabella of the former is somewhat more elongate and there is a wider preglabellar field. The most important differences are found in the pygidia. The pygidium of *P. duplicatus* is more strongly convex (Text Fig. 8 A and B) with a very narrow border zone. Its doublure has a much greater extension. On the upper surface terrace lines are lacking along the border in the posterior part, whereas in *P. perstriatus* the terrace lines reach the border also posteriorly.

Pseudasaphus globifrons EICHW. cannot be identical with *P. duplicatus*, in spite of many common features, as for instance the absence of genal spines. The preglabellar field is narrower and the striation on the doublure on the free cheeks and on the pygidium is much coarser (only 7 lines to each 5 mm).

The terrace lines on the upper surface of the pygidium are more crowded and reach the borders of the pygidium all around, without even becoming scarcer (SCHMIDT 1904, Pl. I Figs. 2 and 5). The doublure reaches the posterior 2/5 of rhachis and its inner border diverges strongly from the rhachis anteriorly. (A form closely resembling *P. globifrons* is found also in Öland [specimen from Hälludden in limestone containing scattered grains of glauconite, belonging to the lower "*Raniceps*" limestone].)

Ptychopyge pahleni, possibly identical with ANGELIN's *Pt. limbata*, shows the dense striation on the doublure but it differs in having the postero-lateral corners of the free cheeks extending backwards as broad spines, in having tubercles behind the eyes, in having a pygidium with a less extensive doublure, more distinct ribs, and a denser system of terrace lines on the upper surface of the test, reaching the border also in the posterior parts.

Occurrence. Öland: Persnäs, at Gunnarslund; Föra: In the drainage ditch west of the railway station (cf. BOHLIN 1949, p. 548).

Niobe ANGELIN 1851

Niobe frontalis (DALMAN). — Pl. VI, Figs. 5—9; Text Fig. 9 B.

Lectotype. A fragmentary specimen, Riksmuseum, Stockholm, Ar. 15970.

Locus typicus. Ljung. Östergötland.

Stratum typicum. *Gigas* limestone. (DALMAN 1828, p. 46: "In calce rubicante".)

Material. Four almost complete cranidia from Öland, a fragmentary one, and five fragmentary pygidia.

Description of material from Öland. Width of cranidium in front of eyes approximately same as at palpebral lobes, and equal to length of glabella + the occipital ring. Width between postero-lateral corners of fixed cheeks less than 1.5 times the anterior width. Anterior border protruding medially in a very obtuse angle. Apart from this slight protrusion the preglabellar field is of equal width in its whole extension until it narrows laterally to end in points a couple of mm in front of the palpebral lobes.

Width of frontal lobe slightly less than length of glabella and 1.5 times the width at posterior end of glabella. Marked preglabellar furrow with slightly impressed antennular pits situated where the furrow bends backwards on sides of frontal lobe. Dorsal furrows rather strongly curved (sides of glabella concave), largely parallel in posterior part to a point opposite glabellar tubercle, from there slightly diverging to notches in front of palpebral lobes, and then strongly to posterior corners of frontal lobe.

On the internal mould a pair of longitudinal impressions for oesophagus muscles on frontal lobe separated by a narrow ridge (specimen III; hardly visible on test of specimen I, nor in specimen II). Glabellar furrows fairly deep: Anterior ones strictly transverse, in specimen III lying 3.5 mm apart in the middle and ending about 1 mm inside notch between frontal and palpebral lobes; in front of them at their lateral ends small oval impressions. Middle glabellar furrows oblique, postero-medial ends opposite anterior part of palpebral lobes, their antero-lateral ends almost reaching lateral ends of anterior furrows. Posterior glabellar furrows also oblique but directed outwards and sligthly backwards, the only ones reaching dorsal furrow. Between posterior pairs of furrows a small glabellar tubercle opposite posterior border of palpebral lobes.

Palpebral lobes small, about as wide as long: length $^1/_4$ the length of the glabella; width of glabella in front of lobes $^2/_3$ of the distance between their lateral borders. Anterior border of palpebral lobes at middle length of cranidium.

Occipital lobes elongate, slightly diverging backwards. Their anterior pointed end a little inside notch at posterior end of palpebral lobes. Posterior branch of facial suture running almost in straight line outwards and somewhat backwards from notch behind palpebral lobe for a distance twice the width of the lobe, then turning backwards in an even bow to posterior marginal furrow and from there straight backwards to posterior border of cranidium. Length of posterior border of fixed cheek $^2/_3$ the distance between dorsal furrows at posterior border of cranidium. Distance from the postpalpebral notch to posterior border about 1.6 times the length of palpebral lobe. Occipital furrow deep, bending around posterior end of occipital lobes and passing into posterior marginal furrows.

Outline of a pygidium from Södvik (Pl. V, Fig. 9) semicircular with rounded antero-lateral angles, almost twice as wide as long. Rhachis thick, anterior width a little less than $^2/_3$ of length, tapering backwards to a point and reaching inner margin of limb; on another pygidium (Pl. V, Fig. 8) seven distinct rings are seen, the two anterior ones transverse, the others running transversely in the middle and downwards and backwards on the sides, an arrangement especially distinct from the 4th segment backwards where median and lateral portions form distinct angles. Tip without rings but its surface flush with that of the segmented part. Ribs 6 pairs, decreasing in size backwards; posterior pair quite small with strictly antero-posterior orientation; all ribs thick, broadly rounded at their distal ends. Width of limb opposite 1st pair of ribs about $^1/_7$ of the width of pygidium. Width of limb posteriorly about half the greatest width.

Smaller variations such as a comparatively broader rhachis, or a distinct break in profile at transition between segmented and unsegmented portions of rhachis, present in two small specimens.

Surface structures of test (Pl. VI, Figs. 6—8; Text Fig. 9): Terrace lines are present on the preglabellar field, on the sides of the frontal lobe (near the preglabellar furrow 10, further inwards 7 to 2 mm), anteriorly on the first lateral glabellar lobe, medially on the second and all over the third and the preserved parts of the occipital ring. Further the fixed cheeks carry a few lines on the anterior border at the postpalpebral notch; there are also lines antero-laterally on the occipital lobes. Lines are lacking medially on the glabella and also laterally on the first and second lateral glabellar lobes, and on the greater part of the free cheeks. There are none on the palpebral lobes. On the preglabellar field the lines run transversely, on its lateral parts, however, with a backwards bend when approaching the preglabellar furrow. On the glabella the lines run largely longitudinally, but they are undulating according to the relief, turning medially in the depressions and laterally on the elevated parts; they diverge distinctly from the sagittal plane on the frontal lobe. They form a network of elongated meshes, though the individual longer and shorter ridges do not actually anastomize, and the intervals between the lines, and parts where the lines are lacking are finely punctuated, with about 45 small pits, distinctly varying in size, per mm^2.

On the sides of the pygidium terrace lines run from the border obliquely backwards to the inner margin of the limb; posteriorly on the limb they are transverse; the ribs have lines across their backs; the bottom of the furrows is punctuated. Material insufficient (for further details, see below).

Measurements of cranidium in mm (1—6, 11—13: Same as in JAANUSSON 1953, pp. 384 f., with alteration indicated in the footnotes). — I—III, *Niobe frontalis*, *Gigas* limestone, Öland (see p. 143 f.). 1, *N. frontalis* Lectotype. Ljung, Östergötland. 2, *Niobe* sp. Lower "*Raniceps*" limestone. Haget (Böda), Öland. U. M. Nr. Ar. 4227. 3—4, *Niobe* sp. *Expansus* limestone: 3, Åketorp (Repplinge), Öland; 4, Lanna, Nerike.

	1	2	3[1]	4	5	6	11[2]	12[3]	13
	Cranidium		Glabella		Occipital W	Fixed cheek	Eye – Eye	Eye-Posterior border of cranidium	Cranidium: greatest width in front
	L	W	L	W					
I	21.0	23.9	17.8	14.0	12.0	6.9	17.2	5.8	17.0
II	22.8	27.5	19	15.7	12.8	7.7	19	7.0	18.9
III	17.8	22.2	15.2	12.1	9.5	6	15	5.0	14.2
1	—	27.0	?19	15.9	12.2	7.7	~18.0	5.8	—
2	29.7	~36	25	18.9	~15.5	10	23.5	8.8	?22.3
3	—	24.6	~21	15	12.0	7.0	19.3	6.9	17.9
4	~28	~33.0	~24	19.2	~16	9.8	24.0	8.0	24.6

[1] Including occipital ring.

[2] Between lateral borders of palpebral lobes.

[3] From inner end of postpalpebral notch to posterior border of cranidium.

[4] Missing or partly missing half of pygidium reconstructed. See p. 146.

Measurements of pygidium in mm (cf. JAANUSSON 1953, p. 386). — a—c, *Niobe frontalis*. *Gigas* limestone: a, Pl. VI, Fig. 9. b, Ljung. Riksmus. Stockholm Ar. 15996. c, same, Ar. 15998. — d, *Niobe* sp. *Expansus* limestone. Lanna, Nerike. U.M. Nr. Ar. 4228.

	a	b	c	d
1. Pygidium. Length	15.1	18.1	18.0	~21.5
2. Pygidium. Width	~30[4]	31.7	36.8[4]	38.8
3. Rhachis. Length	12.9	14.8	15.0	—
4. Rhachis. Width	8.0	9.0	10.1	11.8

Remarks: The material from Ljung is not well preserved. Especially the cranidia are more or less influenced by pressure and slides within the sediment (e.g. Text Fig. 9 B). It is therefore difficult to decide whether small differences from the cranidia from Öland are primary or due to deformation. The material from Öland may not belong to *N. frontalis* as the specimens from Ljung are somewhat unclear in parts important for a comparison.

The preglabellar field is in no specimen complete, but enough preserved to make sure that the terrace lines are arranged largely as in the cranidia from Öland—their transverse course in front of the glabella is especially important. The punctuation of the test is similarly developed. The frontal lobe in the cranidia from Ljung seems to widen more suddenly in front of the palpebral lobes, so that its lateral corners are more protruding. This might be due to deformation, but on the other hand the terrace lines in this place are shorter and cut off the corners, whereas in the cranidia from Öland they run almost parallel to the rather long postero-lateral borders of the frontal lobe. Finally, the occipital furrow is much less pronounced in most of the specimens from Ljung. The deformation may have caused either a deepening of the furrow or it may have smoothed it out. The material from Öland has provisionally been referred to *N. frontalis*, but one must await better preserved specimens from the type locality before an identity can be definitely proved.

The species of *Niobe* formerly described from Sweden and the East Baltic area can, after the structure of the pygidium, be arranged in three groups (there might, however, exist transitional forms). In *N. explanata* the ribs reach the border of the pygidium (ANGELIN 1878, Pl. XI, Fig. 4). In *N. laeviceps*, *obsoleta*, *lindstroemi*, *insignis* (?) and *imparilimbata* n. sp. (see below) the inner margin of the limb forms an even bow. In *N. frontalis* the ribs are more pronounced, and each rib bulges outwards at its distal end, giving the line of demarcation between the central, elevated part and the limb a strongly undulating course. The pygidia from Öland agree well with *N. frontalis* in this and other respects.

In 1901 (p. 107) SCHMIDT describes material from the East Baltic area as *Niobe frontalis* (DALM.). This material comes from the *Expansus* limestone

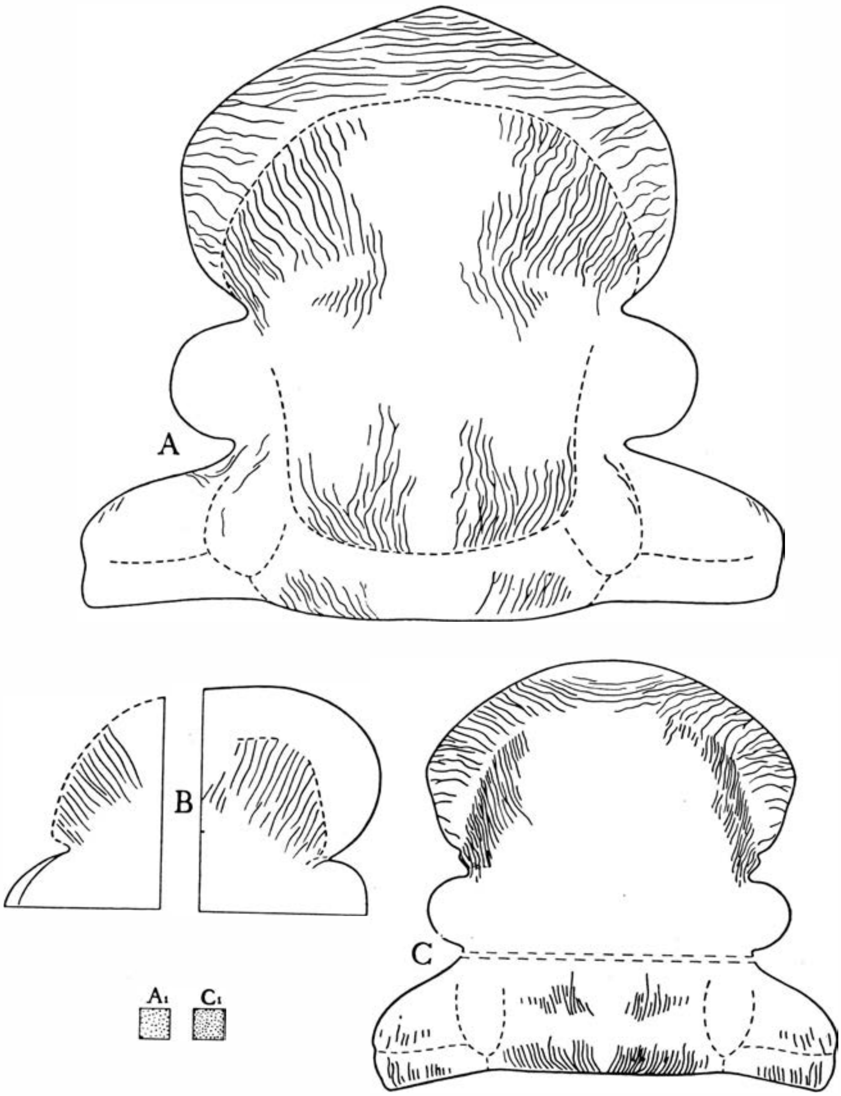


Fig. 9. *Niobe*. Drawn from photographs to show distribution of terrace lines. — *A*, *Niobe frontalis*. *Gigas* limestone. Gunnarslund. Idem Pl. VI, Fig. 7, × 2. *B*, *Niobe frontalis*. Ljung. Östergötland, left R.M. Ar. 15970, right R.M. Ar. 15996. × 2. *C*, *Niobe* sp. (cf. *frontalis* sens. SCHMIDT). *Expansus* limestone. Combined from specimens from Åketorp, Repplinge, Öland, U.M. Nr. Ar. 4248 (posterior part, approximately × 2) and Lanna, Nerike, U.M. Nr. Ar. 4228 (anterior part, surface of central parts damaged, × 1.5). — A_1 and C_1, squares of 1 mm² showing the density of the punctuation in *N. frontalis*, U.M. Nr. Ar. 4249 and N. sp. U.M. Nr. Ar. 4248. From the middle 1 mm in front of the occipital furrow. × 4.

and the lowermost part of the "*Raniceps*" limestone; already its occurence at such low levels makes it probable that SCHMIDT's species is not identical with *N. frontalis*.

It is not my intention to discuss SCHMIDT's material here. There occurs, however, in the *Expansus* limestone in Sweden a form, represented by a poorly preserved cranidium from Repplinge (Öland) and a complete but somewhat distorted specimen from Lanna (Nerike), which agrees in some respects with SCHMIDT's figures though it might belong to another species than his material.

The cranidium differs from *N. frontalis* in the following respects: The frontal lobe is more elongate, delimited by an almost semicircular preglabellar furrow; the palpebral lobes are smaller (smaller eyes); the occipital furrow is only just distinguishable. The terrace lines on the preglabellar field run obliquely forwards and outwards from the glabellar furrow to the facial suture, joining in the middle to form wide bows open forwards (Text Fig. 9 C); on the frontal lobe their course is almost strictly parasagittal, and the striation is denser than in *N. frontalis* (10 lines to 2 mm, also at some distance from the preglabellar furrow); there are distinct terrace lines on the occipital ring and posteriorly on the fixed cheeks (in *N. frontalis* only on the occipital ring). The punctuation is finer and denser—in front of the occipital ring about 65 to the mm^2, instead of about 45 in the same place in *N. frontalis* (Text Fig. 9 A_1 and C_1). In SCHMIDT's figure (Taf. IX, Fig. 11) the same elongate frontal lobe is seen, but the shape of the preglabellar field is somewhat different (anterior border less curved)—the Swedish specimens also differ somewhat from each other in this respect.

The pygidium belonging to the specimen from Lanna is of the "*frontalis* type". A detailed comparison with *N. frontalis* cannot be made as of neither species sufficiently well preserved specimens are available. The Lanna specimen shows, however, a coarser and more extensive system of terrace lines than the best preserved specimen from Ljung.

The pygidium in Plate VI, Fig. 10 comes from a rather low level of the "*Raniceps*" limestone. It resembles the pygidium of *N. frontalis*, but the unsegmented portion of the rhachis is distinctly set off from the segmented part, abruptly sloping down from it. The specimen is quite small, but the same development of the rhachis is seen in large pygidia. It is, however, also present in small pygidia from the *Gigas* limestone in Öland and it is at present impossible to decide if *N. frontalis* occurs also in the "*Raniceps*" limestone.

Occurrence. *Niobe frontalis* has until now been found with certainty only in the *Gigas* limestone.

Östergötland: Ljung.

Öland: See p. 128.

Niobe imparilimbata nov. sp. — Pl. VI, Figs. 10 and 11.

Holotype. A pygidium (Pl. VI, Fig. 10). U.M. Nr. Ar. 4230.

Locus typicus. Parish of Böda. The type specimen derives from the boring at Böda hamn, but as there is no exposure of the *Limbata* limestone there, Böda hamn cannot very well be given as type locality.

Stratum typicum. Lower part of *Limbata*-limestone.

Derivatio nominis. From the very unequal width of the limb.

Diagnosis. Pygidium broad, somewhat flattened but with strongly convex rhachis. Limb broad on the sides, very narrow behind; three pairs of faint ribs. Structure on test: A dense fine punctuation, marked terrace lines on the limb, a few faint lines on pygidial rings and ribs.

Material. A free cheek, a pygidium (type). Some pygidia from Middle Öland evidently belong to this species.

Description. The free cheek (Pl. VI, Fig. 11; found at the same level as the type specimen; lacks the parts in front of the eye; further, the part along the posterior branch of the facial suture is crushed and it is uncertain whether it is complete): The eyes are small, antero-posterior diameter less than $^1/_2$ the distance from the eye to the postero-lateral corner. The ridge running from this corner to antero-lateral corner of frontal lobe broad and rather prominent, halfway between eye and postero-lateral corner about as wide as the marginal zone outside it.

Pygidium almost exactly twice as broad as long. Rhachis strongly convex in $^4/_5$ of its length, the posterior $^1/_5$ forming a low narrow ridge. Anterior width of rhachis $^4/_7$ of total length. On the type specimen the segmentation of the rhachis is partly obscured by a fracture; in a specimen from Repplinge seven rings can be counted on the more elevated part (excluding the extreme posterior end of this part). The low, terminal portion is evidently unsegmented. There seems to be three pairs of ribs (in the type only the most anterior pair is distinct), the posterior one very short. The doublure is broad, extending forwards along the posterior $^1/_3$ of the rhachis, limiting the area, where the faint ribs can be traced, to a small triangle. Limb in its widest part (on the sides) almost three times as wide as opposite posterior end of rhachis.

Terrace lines well developed on the pygidial facets and the limb (not in the depression separating this from side lobes). Faint lines in semicircular arrangement on centre of pygidial rings, almost no lines on sides of these rings, and short lines across the back of the ribs. In a specimen from Repplinge there are no terrace lines on the side lobes. On the free cheek terrace lines occur along the free border.

The test is covered by a fine dense punctuation, on the free cheek of small pits of varying size, on the pygidium more uniform.

Remarks. Similar material from about the same level has been referred by WIMAN to *Niobe laeviceps* DALMAN. The pygidium from Böda hamn has been compared with two specimens of *N. laeviceps* collected by DALMAN at the type locality, Husbyfjöl in Östergötland. These agree with DALMAN's description and also fairly well with his Pl. IV, Figs. 1 a—d. Though none of them might be the original of these figures, there is no doubt that both are referable to DALMAN's species. The specimens belong to Naturhistoriska Riksmuseet, Stockholm, and have the numbers Ar. 46000 and Ar. 46001 (in the former the pygidium is best preserved, in the latter the cephalon).

The eyes in *N. laeviceps* are large, antero-posterior diameter about $^2/_3$ the distance from eye to postero-lateral corner. The ridge between this corner and the frontal lobe is not as prominent as in *N. imparilimbata*, its width halfway between eye and posterior corner being only half the width of the marginal zone at this point.

The pygidium has approximately the same proportions as in *N. imparilimbata*, but the rhachis is broader, width anteriorly compared with total length as 5.5: 7. Posterior end broadly rounded (somewhat unclear in the hindmost part). No ribs distinguishable on side lobes. Inner margin of limb subparallel with free border.

Terrace lines on free cheeks evidently as in *N. imparilimbata*, though perhaps somewhat more spaced, on pygidium present only on the external half of the width of the limb. The test shows, on the cranidium as well as on the pygidium, a characteristic punctuation of scattered somewhat larger pits, and between them smaller pits; these structures together not by far as dense as in *N. imparilimbata*; on the pygidium, however, the punctuation seems to be denser on the limb than on the central portions.

It may be added that most specimens described or mentioned from Sweden as *N. laeviceps* (e.g. by WIMAN in 1906) probably belong to other species. Unfortunately, the test is often recrystallized, a process which has deleted the fine structural details; even the terrace lines may then be no longer visible. The species described from Ottenby by MOBERG and SEGERBERG 1906 belongs to *N. obsoleta* or a form closely related to this species.

Some pygidia from the North Baltic area (WIMAN's collection) might belong to *N. imparilimbata*. They differ, however, in some details and the discussion of this material had better be postponed until a revision of all the forms from the *Limbata* limestone can be made.

Other specimens which closely resemble *Niobe imparilimbata* were recently described from Norway as *Niobe laeviceps* (SKJESETH 1953).

To judge from the figures, other forms described from the *Limbata* limestone and lower levels as *N. insignis*, *obsoleta* and *lindstroemi* have a nearly semicircular pygidium, with a limb of almost equal width in its whole extension. Later discoveries have shown that the older species of *Niobe* form a complex very difficult to disentangle, and the examination of all the new material will undoubtedly increase the number of species considerably. *N. imparilimbata*, described here, might serve as a fixed point from which the revision can start. Before this revision has been completed nothing can be said about the value of the new species as an index fossil.

Occurrence. Böda: Böda hamn boring. Repplinge: Quarry about 1 ½ km N.W. of Tryggestad. Torslunda: Kråketorp (a small pygidium very similar to the type specimen, but structure on test not distinct).

Description of the Microlithology of the Lower Ordovician Limestones between the *Ceratopyge* Shale and the *Platyurus* Limestone

By

Valdar Jaanusson

Cf. Plates VII—X

For the study of the microlithology of the limestones thin sections, chemical analyses of certain elements, and analyses of insoluble residue have been made for each half metre of the core.[1] As described above by Dr. BOHLIN the limestones of this portion of the core show already macroscopically a considerable variation as to the distribution and concentration of the various authigenic minerals, which are often concentrated in some thin layers or spots but almost lacking in adjacent layers. Thus the above-mentioned analyses which had been made regularily at each half metre of the core, characterize only small portions of the section, and it must be taken into consideration that for this reason the results of the analyses do not always correspond to the average composition of the limestones within the respective macrolithologically defined division. This proviso applies especially to the thin sections where only a small portion of the total height of the section is accessible to investigation.

In the core portion studied, the following macrolithological main divisions can be distinguished (within brackets the lithological denominations of the limestones based on particle size according to the present writer; regarding the definitions of the terms cf. JAANUSSON 1952).

m. 23.42—25.27 m Brownish red and greyish green variegated limestone (mostly recrystallized calcarenite).
l. 25.27—26.60 m Pale brownish grey and grey variegated limestone (recrystallized calcarenite).
k. 26.60—27.79 m Light grey limestone (recrystallized calcarenite).
j. 27.79—30.83 m Light grey glauconitiferous limestone (recrystallized calcarenite).
i. 30.83—31.40 m Grey limestone rich (in the lowermost layers very rich) in glauconite (recrystallized calcarenite).

[1] The chemical analyses have been carried out at the Paleontological Institute by Mr. J. LUKINS, Dipl. Ing., assisted by Mrs. E. LUKINA, under the supervision of Prof. I. HESSLAND. The analyses of the total amount of the insoluble residue, as well as the sieving of its coarse fractions, have been made by Miss M. WALLIN at the same Institute.

h. 31.40—31.46 m Calcareous glauconite sandstone.
g. 31.46—31.83 m Grey limestone very rich in glauconite (recrystallized calcarenite).
f. 31.83—34.33 m Grey limestone rich in glauconite (recrystallized calcarenite).
e. 34.33—34.86 m Alternating light brownish red and grey layers of glauconitiferous limestone (calcarenite).
d. 34.86—35.73 m Intensely brownish red limestone (calcarenaceous calcilutite).
c. 35.73—38.08 m Alternating pale brownish red and grey layers of limestone (calcarenaceous calcilutite).
b. 38.08—39.00 m Grey limestone (calcilutite).
a. 39.00—39.15 m Grey limestone, in the upper part rich and, in the lower part, very rich in glauconite.

Underlain by the *Ceratopyge* shale (cf. WÆRN 1952).

According to BOHLIN (cf. Text Fig. 3) division *m* belongs to the *Gigas* and *Obtusicauda* limestones, divisions *k, j,* and probably also *l*, to the "*Raniceps*" limestone. Divisions *g, h,* and *i* belong to the *Expansus* limestone (divisions *g* to *m* thus to the *Vaginatum* group), division *f* to the *Lepidurus* limestone, divisions *d* and *c* to the *Limbata* limestone, and divisions *b* and *a* to the Upper "*Planilimbata*" limestone. The exact stratigraphical attribution of division *e* has as yet not been ascertained on account of the scarcity of determinable macrofossils in this division of the core.

In studying the microlithology of this portion of the core the same methods have been used as on the uppermost part of the core (to be described later; cf. also JAANUSSON & MUTVEI 1953). Regarding the methods of analysis of iron, sulphur, and phosphorus see HESSLAND (1955).

I. Particle Size and Microstructure of the Limestone

The particle size of the fossil fragments has been measured according to the method described by JAANUSSON (1952).[1] The results are shown in Text Fig. 10.

Based on particle size and microstructure two main types of limestone may be distinguished:

1. The core between 23.42 m and 34.86 m (div. *e—m*), corresponding to the *Vaginatum* and the *Lepidurus* limestones, consists of mostly recrystallized calcarenites.

2. The core between 34.86 m and 39.00 m (div. *b—d*), corresponding to the *Limbata* and Upper "*Planilimbata*" limestones, consists of calcilutite. The particle size of the limestone of the division *a* (39.00—39.15 m) has not been studied.

1. 23.42—34.86 m (divisions *e—m*). In most thin sections the groundmass is coarsely crystalline, the fossil fragments are strongly recrystallized and partly fused with the groundmass (cf. Pl. VIII, Figs. 1 and 4). Measurement

[1] The measurements have been carried out partly by Mr. R. HINNO and partly by the present writer.

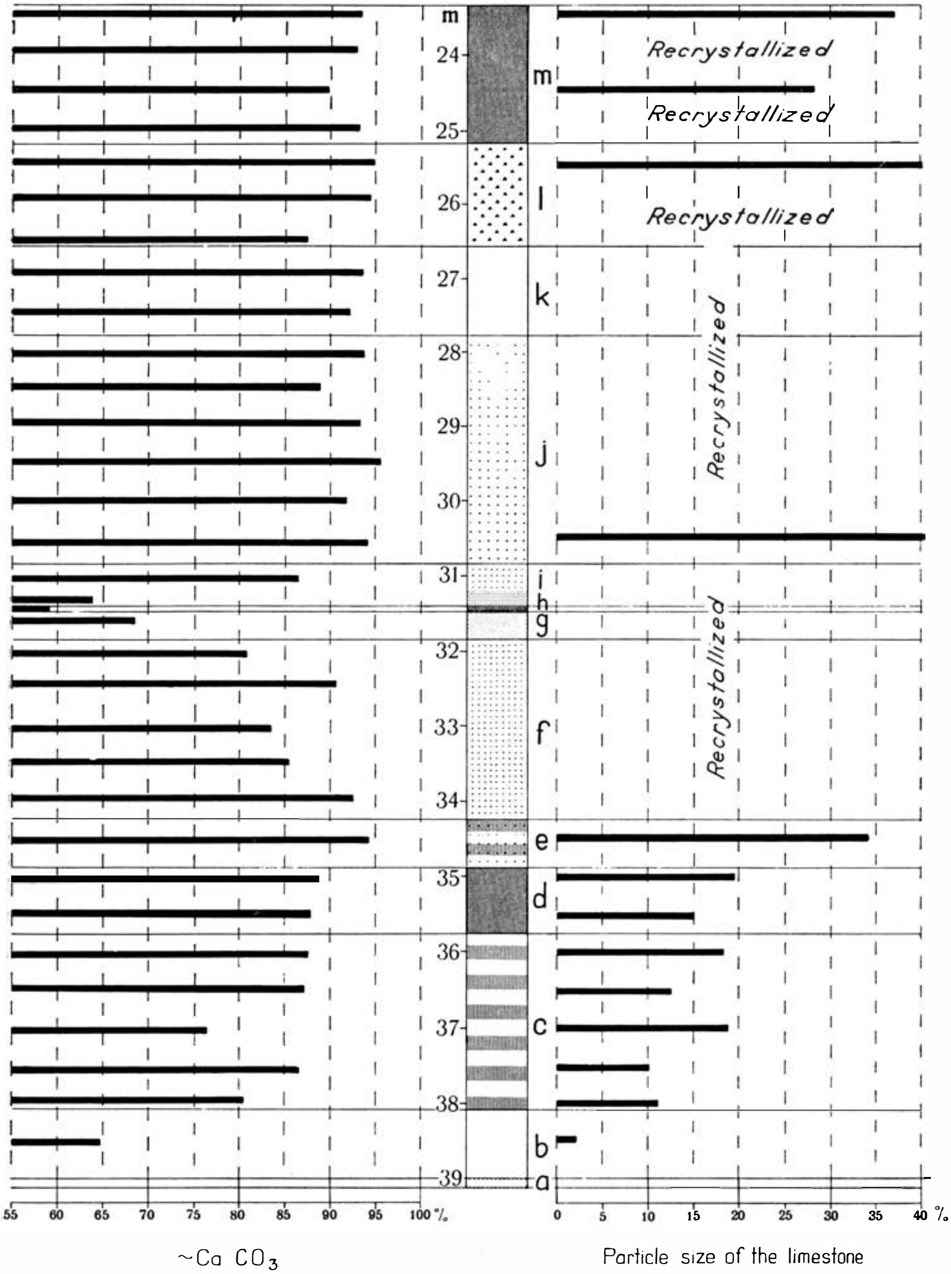


Fig. 10. To the left the material soluble in dilute acetic acid, *i.e.* approximatively calcium carbonate. To the right the particle size of the limestone according to the method of JAANUSSON 1952. For the signs see explanation to fig. 2, p. 122.

of particle size was thus not possible in these thin sections. At some levels, however, viz. at 23.5 m, 24.5 m, 25.5 m (cf. Pl. VII, Fig. 1), and 30.5 m (cf. Pl. VII, Fig. 2), parts of the thin sections are less recrystallized and the measurements carried out there show a rather high percentage of fossil fragments longer than 0.1 mm (cf. Fig. 10). The thin sections of the more thoroughly recrystallized limestones also show a considerable particle size (cf. Pl. VIII, Fig. 1), though not measurable on account of extensive recrystallization.

Fossil fragments of less recrystallized limestone portions have as a rule angular outlines (cf. Pl. VII, Fig. 1 and Pl. VIII, Fig. 2), and sometimes whole uncrushed shells of small fossils, usually ostracods, can be met with. No distinct sorting of the shell debris can be observed. The limestone apparently consists mainly of autochthonous or par-autochthonous shell material, accumulated at or near the place of its origin. After the deposition a more or less extensive recrystallization has taken place, probably owing to the great permeability of the rather coarse shell sand. In one thin section, however, viz. at the level of 30.5 m, the fossil fragments are more crushed and somewhat rounded, and there the shell sand seems to be rather well sorted (cf. Pl. VII, Fig. 2).

2. 34.86—30.00 m (divisions *b*—*d*). The groundmass is finely crystalline and the fossil fragments generally have distinct outlines (cf. Pl. VII, Figs. 3 and 4). In the divisions *c* and *d* (*Limbata* limestone) the amount of the fossil fragments longer than 0.1 mm is still fairly high (cf. Fig. 10) and the limestone may be classified as calcarenaceous calcilutite; in division *b*, in the sole thin section measured, the amount of fossil fragments of "sand size" is very low. In this portion of the core the fossil fragments have angular outlines, and complete shells of small fossils are not uncommon. The greatest part of the calcium carbonate in the limestone of these divisions seems to consist of probably chemically or biochemically precipitated lime mud.

II. Distribution of the Authigenic Substances in the Thin Sections

The groundmass of the limestones studied is usually impregnated in isolated spots with various authigenic substances which also occur as grains, fillings in small shells, or as coatings on fossil fragments. The various substances have been distinguished mainly according to their colour under the microscope in incident light, which makes the different colours more easily distinguishable than transmitted light. The following substances have been distinguished:

1. Brownish red substance, mostly ferric oxide (haematite) (cf. also HADDING 1932, e.g. pp. 49—50). In division *d*, the whole groundmass is finely and more or less evenly impregnated with this substance. In division *m* and the uppermost part of division *c*, only spots of it can be observed. The same

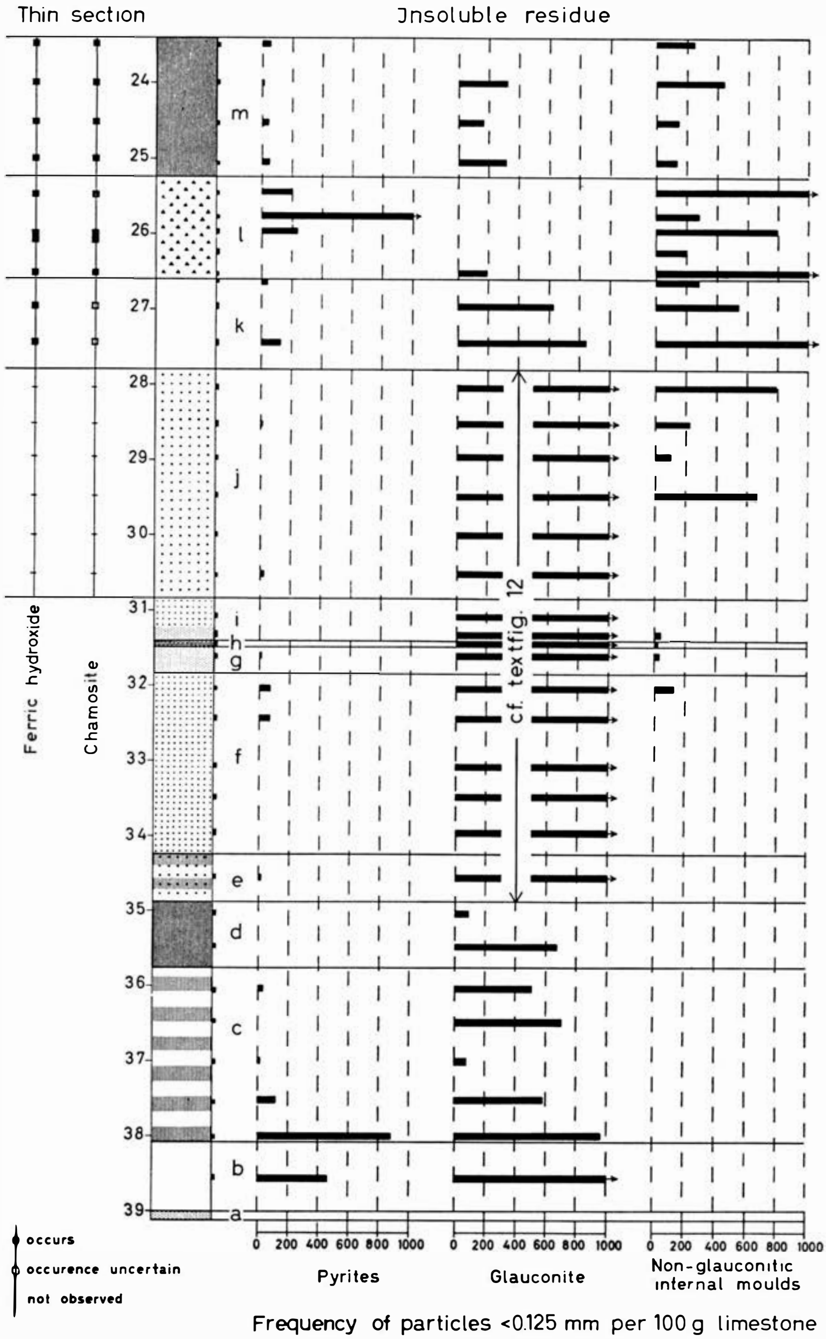


Fig. 11. Distribution of some of the commonest authigenic minerals in the thin sections and in the "sand fraction" of the insoluble residue.

substance probably causes the pale brownish red colour of parts of divisions *c* and *e*; it has, however, not been recognized in the thin sections studied.

2. Yellow, hydrous ferric oxide. In divisions *k*, *l*, and *m*, this substance seems to be derived from decomposed chamosite as it nearly almost occurs together with this iron silicate (cf. Text Fig. 11). It usually surrounds the concentrations of chamosite, which it sometimes distinctly substitutes. A more or less continuous transition from the pale green colour of the chamosite to the clear yellow colour of the hydrous ferric oxide could also be observed.

At the level 34.5 m a thin layer impregnated with the yellow substance has been observed in the thin section, without distinct boundaries either above or below. The glauconite grains in this layer are strongly altered, and sometimes a continuous transititon may be observed from the more or less fresh green colour of the glauconite to the clear yellow colour of the hydrous ferric oxide, surrounding the glauconite grain; the fissures and cracks in the glauconite grains are also usually filled with hydrous ferric oxide.

3. In divisions *f*, *i*, *j*, *k*, and *l*, a substance of more or less dark brown colour in incident light occurs, partly as small nodules and as fillings of small shells or narrow cavities of Echinoderm fragments, and partly as an impregnation of more argillaceous layers in thin sections. In the case of nodules this substance is probably phosphorite; the composition of the impregnation, on the other hand, is more uncertain, but it may also be of the same nature. The substance occurs most frequently in division *l*, where dark brown fillings of small shells are occasionally fairly abundant.

4. Chamosite. This mineral which has a pale green colour in incident as well as in transmitted light agrees in colour and appearance with the chamosite in the lowermost *Schroeteri* beds of the Siljan district, determined by X-ray analysis (cf. JAANUSSON & MUTVEI 1953, p. 396). It appears as fillings of small shells or cavities of Echinoderm fragments, sometimes also as a thin coating around the fossil fragments, usually together with hydrous ferric oxide (cf. above). In the thin sections studied chamosite has been observed in divisions *l* and *m* (cf. Fig. 11), and in division *k* there occur in the concentrations of hydrous ferric oxide traces of greenish colour, which may indicate the same mineral. It is, furthermore, possible that at least part of the small internal moulds observed in the insoluble residue of divisions *f*—*i* (cf. Fig. 11) consists of chamosite but that they have not been represented in the thin section on account of their relative scarcity.

5. Pyrites. Most of the pyrites observed as small grains, less than 0.1 mm in diameter. In divisions *f*, *i* and *j* it usually occurs together with glauconite grains, in the shape of small nodules around the glauconite grains or sometimes even within such grains. As a rule only a few grains have been observed in each thin section, except in division *b* and the lower part of division *c* where pyrites occurs abundantly.

6. Glauconite. Glauconite grains have been met with in divisions *a*, *b*, *e*, *f*, *g*, *i*, and *j* in all thin sections studied.

In the lowermost part of division *a*, consisting of a calcareous glauconite sandstone, immediately above the *Ceratopyge* shale, the glauconite grains are distinctly rounded, slightly angular or sometimes tabular. Besides, there occur some phosphorite nodules and fairly abundant quartz grains up to 0.25 mm in diameter, some of which are rounded, while others are quite angular. This is the only layer of the limestones studied where quartz grains have been met with in any abundance. A few angular glauconite grains have also been observed in the thin section studied of the limestone of division *b*.

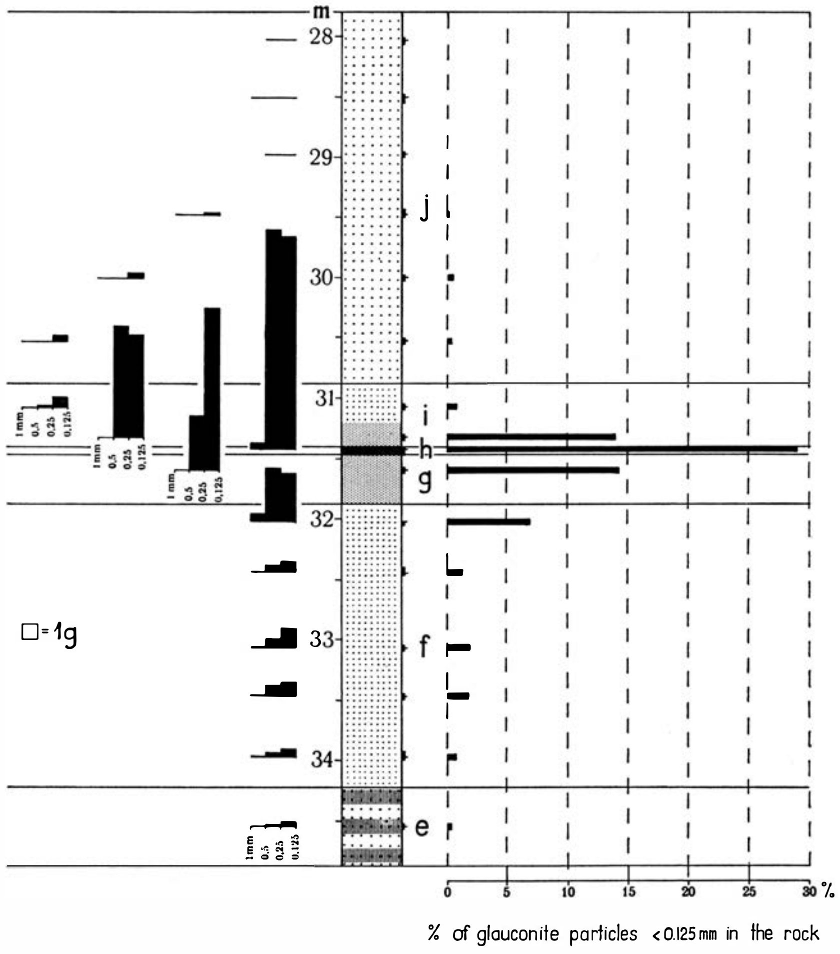
In divisions *e*, *f*, and *g*, many of the grains have an unevenly lobate outline (cf. e.g. Pl. VIII, Fig. 4) and often also deep cracks ("grains full of cracks", cf. HADDING 1932, p. 93). Besides, there also occur smaller grains in which one side is even and the other sides are uneven and cracked. These grains may be considered as fragments of larger cracked grains (HADDING 1932). Furthermore the glauconite in these divisions sometimes occurs as fillings of small shells or canals of Echinoderm fragments, especially in the lower part of division *f* and in division *e* (cf. Pl. VIII, Fig. 4). Grains with well-developed cracks are abundant in divisions *e* and *f*, whereas in division *g* (at the level 31.46—31.53 m) cracked grains are scarcer and glauconite grains with rounded outlines occur more frequently (cf. Pl. VIII, Fig. 3).

In divisions *i* and *j* most glauconite grains have distinctly rounded or slightly angular outlines (cf. e.g. Pl. VIII, Fig. 2). Some Echinoderm fragments with canals filled with glauconite have, however, also been observed.

III. The "Sand Fraction" (> 0.125 mm) of the Insoluble Residue

The amount of the fraction >0.125 mm of the limestone insoluble in dilute acetic acid is rather variable, chiefly owing to the uneven distribution of the glauconite particles. The amount of glauconite in the "sand fraction" in beds rich in glauconite (divisions *e*—*j*) is shown in Fig. 12. In the overlying and underlying beds the total amount of the "sand fraction" of the insoluble residue is very low, except in the bottommost layers of the limestone of the core (division *a*), which partly consists of calcareous glauconite sand.

The insoluble fraction >0.125 mm contains, apart from secondary grains of clay substance and, at some levels, pieces of shale, mainly the following particles: (1) Allochthonous mineral grains, (2) Pyrites, (3) Glauconite, (4) Non-glauconitic internal moulds of small fossils, and (5) Insoluble microfossils. The microfossils have not been considered in the present paper. Allochthonous mineral grains occur with apparantly relatively very small quantitative variation through the whole section, and have not been studied quantitatively. To get a picture of the quantitative distribution of the other



Fig, 12. To the left the granulometrical distribution of the glauconite particles < 0.125 mm per 100 g limestone; to the right the weight percentage of the glauconite particles < 0.125 mm in the rock. The insoluble residue of 100 g limestone has been sieved, the different fractions < 0.125 mm weighed, and the percentage of the non-glauconitic particles calculated by counting of about 200—300 grains of each fraction. The percentage corresponding to the non-glauconitic particles from each fraction has been omitted from the graph.

particles, their frequency has been determined by counting the number of particles in the "sand fraction" of 100 g limestone in each layer studied lithologically (cf. Fig. 11).

1. *Allochthonous mineral grains,* chiefly quartz, occur in the limestone in very small and seemingly more or less constant quantities throughout the whole portion of the core. At the level 24.0 m, however, the amount of these grains in the insoluble residue seems to be greater than at other levels studied. The grains there show mostly an angular shape without any trace of rounding. Furthermore, in the basal limestone layer of the core, the in-

soluble residue of which has not been studied, the amount of allochthonous mineral grains is rather high as may be seen in the thin sections (cf. p. 157).

2. *Pyrites.* — In the "sand fraction" of the insoluble residue pyrites is most abundant in division *b*[1] and the lower part of division *c*. This corresponds also with the observations in the thin sections (cf. p. 156) and with the distinct rise of the sulphur contents (cf. Text Fig. 14) at the same levels. At the level of 37.5 m cubes and pyritoëders of pyrites have been observed. Otherwise it occurs mainly in the form of small crystal aggregates.

3. *Glauconite.* — In the insoluble residue of divisions *d*, *k*, *l*, *m*, and the uppermost part of *c*, there occur occasionally small amounts of glauconite grains (cf. Fig. 11), which probably have allochthonous origin.

From division *a*, partly developed as a glauconite sandstone, only one thin section has been studied (cf. p. 157).

In division *b* and the lowermost part of division *c* (at the level of 38.0 m) the glauconite grains are generally angular, one side being often evenly curved and darker, the other sides uneven and paler. Only a few glauconite internal moulds have been observed (10—20 per 100 g limestone). In the limestone of division *b* there occur also thin coatings of glauconite on bedding planes (cf. BOHLIN, above), and it is possible that some of the glauconite grains have been derived from these glauconite crusts, crushed during the treatment of the "sand fraction" of the insoluble residue. The glauconite crusts certainly are autochthonous and thus the glauconite in this part of the core seems to have mostly the same origin. This is probably the case also with the glauconite in the lowermost part of division *c*.

The quantitative distribution of the glauconite particles in divisions *e*—*j* is shown in Fig. 12. As may be seen from Fig. 13, a great amount of the glauconite in the lower part of this sequence of strata (divisions *e* and *f*) occurs in the form of glauconite internal moulds, at the level of 34.5 m more than half of the total amount of the glauconite particles. Upwards the relative amount of the glauconite internal moulds decreases, and in divisions *h* and *i* they are almost completely lacking. The glauconite internal moulds belong mainly to gastropods, but hyolithids and some other groups also occur (cf. Pl. X, Fig. 2).[2] The glauconite grains occurring in divisions *e* and *f* are for the most part full of cracks in the fraction 1—0.5 mm, and angular in the fractions 0.5—0.25 mm (cf. Pl. IX, Figs. 3—4) and 0.25—0.125 mm, but

[1] Although the number of pyrites particles in the layer studied (at the level of 38.5 m) s not large (cf. Fig. 11), the total amount of pyrites is rather high, owing to the relatively large size of most of the individual particles in this layer. At the level of 25.75—25.79 m, however, the number of individual particles of pyrites is large (> 1000 per 100 g limestone) but the size of the particles is small throughout.

[2] Glauconite internal moulds of the same type have been described from Lower Ordovician beds of Estonia, Ingermanland and North German erratic boulders by EHRENBERG (1858, 1861), BÖRLING (1904, according to LAMANSKY 1905, pp. 2 and 148), and EISENACK (1932).

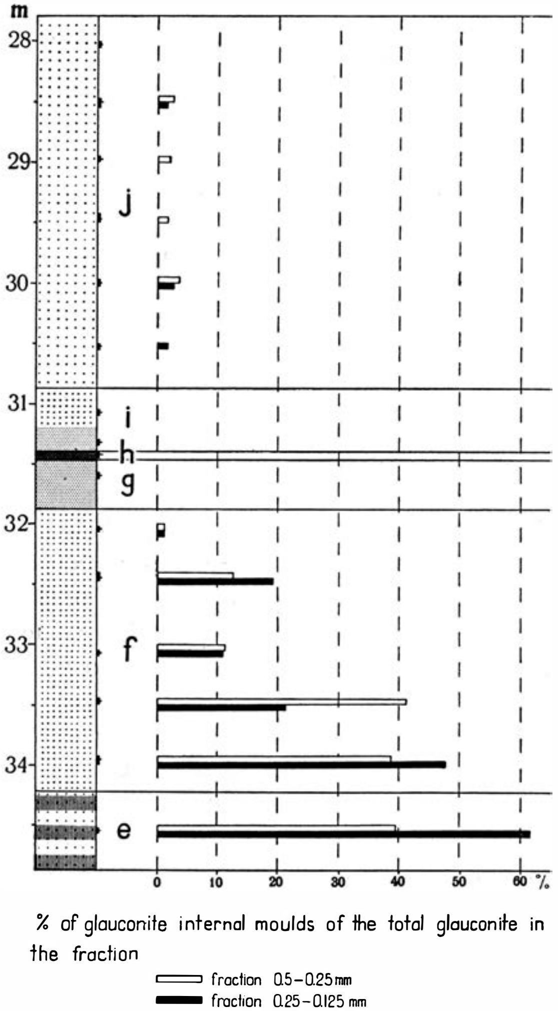


Fig. 13. Percentage of the glauconite internal moulds of the total glauconite in the fractions 0.5—0.25 mm and 0.25—0.125 mm. — The percentage of the internal moulds has been calculated by counting of 200—300 glauconite particles from each fraction studied.

a few more or less rounded grains can also occasionally be met with; some of these grains certainly are fragments of internal moulds. Some of the angular grains are fragments of cracked grains, being probably partly crushed during the sieving of the insoluble residue, as such grains are rather easily broken. Other small angular grains, however, seem to have kept their original shape and the explanation of their having shallower cracks than the larger grains lies obviously in the fact that on account of the smaller volume of the grains their surface did not contract so much at the dehydration process as that of the larger grains. Most glauconite particles in divisions *e* and *f* obviously are autochthonous as the delicate grains full of cracks do not seem to resist a longer transportation without breaking up and as the glauconite there often occurs as fillings of small shells or cavities of Echinoderm fragments.

In divisions *i* and *j* there occur only few glauconite internal moulds, most of them having a worn appearance. The glauconite grains are mostly distinctly rounded or slightly furrowed and have often a shining surface (cf. Pl. IX, Figs. 1—2). These glauconite grains seem to be for the most part allochthonous or par-autochthonous.

In division *h* (at the level 31.40—31.46 m) both kinds of glauconite grains, cracked and rounded together with intermediate stages, occur, and in this layer most glauconite grains probably are par-autochthonous, having been transported only a short distance and accumulated or concentrated in this layer of calcareous glauconite sand.

4. *Non-glauconitic internal moulds.* — In divisions *j*, *k*, *l* and *m* there appear in the insoluble residue varying quantities of small internal moulds of several groups of animals (gastropods, ostracods, hyolithids, etc., cf. Pl. X, Fig. 1). The substance which fills the small shells of these animals seems to be mainly chamosite and in some layers probably also phosphorite. The vertical distribution and the frequency of these internal moulds are shown in Fig. 11.

IV. Notes on the Distribution of Iron, Phosphorus, and Sulphur

The average value of total iron as Fe_2O_3 in the limestones between the *Ceratopyge* shale and the *Platyurus* limestone amounts to 2.65 %. The distribution of the iron is rather uniform through the section except the beds comparatively rich in glauconite (divisions *g*—*i* and the uppermost part of division *f*), where the contents of iron are higher and at the same time more or less proportional to the abundance of glauconite (compare Figs. 14 and 12).

The average value of phosphorus as P_2O_5 in this portion of the core is 0.26 %. Agreeing with the iron the contents of phosphorus in the glauconitiferous *Lepidurus* and *Expansus* calcarenites (div. *f*—*i*) are roughly proportional to the abundance of glauconite, being highest at the culmination of the glauconite particles and the iron. Several layers of the "*Raniceps*" limestone also show a rather high content of phosphorus, its distribution in these beds being, however, rather uneven. The calcilutites of the Upper "*Planilimbata*" and *Limbata* beds (div. *b*—*d*) are comparatively poor in phosphorus with an average value of 0.09 % (9 analyses), and the same is the case with the uppermost brownish red calcarenites of the *Vaginatum* group (div. *m*) (cf. Text Fig. 14).

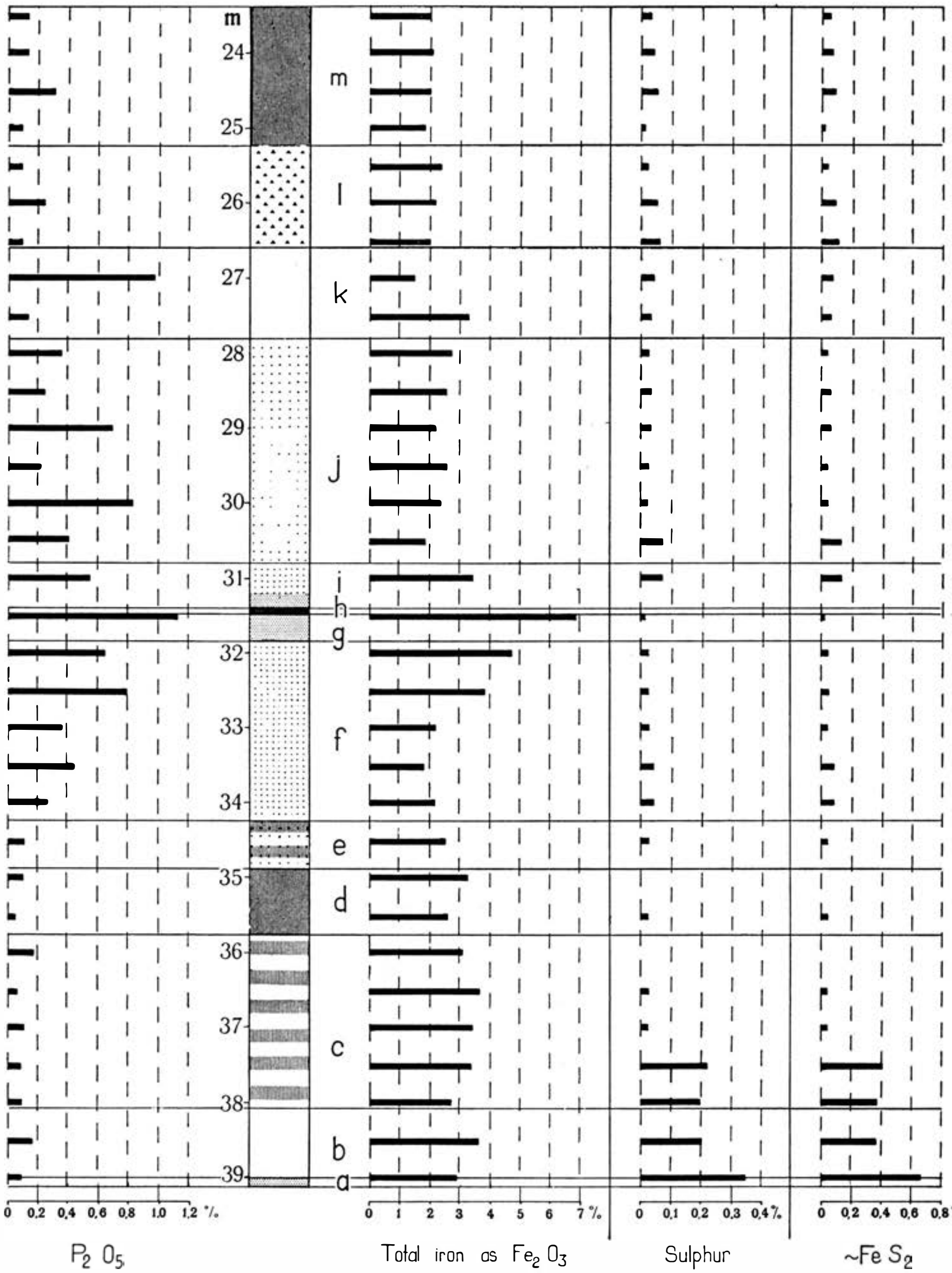


Fig. 14. Analyses of phosphorus, iron, and sulphur. The contents of FeS_2 have been calculated from the analyses of sulphur under the assumption that all sulphur occurs in form of ferrous sulphide.

The contents of sulphur are rather low and more or less uniform through most parts of the core. Only in divisions *a*, *b* and the lowermost part of *c* sulphur occurs in more considerable quantities. The abundance of sulphur in these beds is in accordance with the observed abundance of pyrites in the insoluble residue of the same beds (cf. Figs. 11 and 14).

Summary

The main results of the study of the microlithology of the core limestones between the *Ceratopyge* shale and the *Platyurus* limestone are as follows:–

1. The lowermost limestones studied (div. *b*, *c* and *d*) can be classified as calcilutites in the sense of JAANUSSON (1952). In the *Limbata* limestone (div. *c* and *d*), however, the lime mud was mixed with considerable amounts of shell debris and there the rock can, therefore, be called a calcarenaceous calcilutite. At the beginning of division *e* (probably forming the base of the *Lepidurus* limestone) the conditions of sedimentation changed and instead of lime mud deposition of a sandy sediment consisting largely of calcareous shell fragments started and continued from there up to the top of the *Vaginatum* limestone. After the deposition the calcareous shell sand has undergone a strong recrystallization and most parts of the rock can therefore be called a recrystallized calcarenite.

2. Deposition of the Upper "*Planilimbata*" limestone on the eroded surface of the *Ceratopyge* shale began with an accumulation of glauconite sand, consisting mainly of rounded or tabular allochthonous glauconite grains and including relatively large quartz grains and phosphorite nodules (lowermost part of division *a*).[1] Upwards the contents of glauconite diminish (upper part of div. *a*, and div. *b*), and still higher (div. *c* and *d*) the limestone contains only small amounts of glauconite. In division *e*, formation of relatively large amounts of glauconite began again, increasing upwards through the *Lepidurus* (div. *f*) and the lower part of the *Expansus* limestone (div. *g*). The accumulation of glauconite grains culminated in a layer of calcareous glauco-

[1] The boundary between the *Ceratopyge* shale and Upper "*Planilimbata*" limestone (lower boundary of the division *a*, at the level 39.15 m of the core) as drawn in the present paper corresponds to the boundary between the divisions *b* and *c* in Fig. 1 of HESSLAND (1955, p. 74). The *Ceratopyge* limestone and the Lower "*Planilimbata*" limestone (cf. TJERNVIK 1952), well developed e.g. in southernmost Öland, are missing at Böda Hamn, and the above-mentioned boundary thus denotes a considerable hiatus. The distribution of iron, phosphorus, and calcareous substances as well as of glauconite etc. in the layers on both sides of the boundary has been described and discussed by HESSLAND (1955, "Transitional layers", pp. 73—75, 88—89). Unfortunately the important hiatus between the *Ceratopyge* shale and Upper "*Planilimbata*" limestone has not been stressed in his diagram (p. 74, Fig. 1) or text as HESSLAND's paper went to press at a time when the calcareous upper part of the Böda Hamn core had not yet been studied in detail.

nite sand in the middle of the *Expansus* limestone (div. *h*), the glauconite there, however, probably being par-autochthonous, transported and secondarily concentrated. Upwards, through the uppermost part of the *Expansus* (div. *i*) and the lowermost part of the "*Raniceps*" limestone (div. j), the contents of glauconite grains in the limestone decrease successively, and the grains are there at least in part allochthonous, transported, rounded and secondarily deposited.

3. An iron silicate, showing the same colour and appearance as the röntgenographically determined chamosite from the lowermost *Schroeteri* limestone at Vikarbyn, Siljan district (cf. JAANUSSON & MUTVEI 1953, p. 396) appears in thin sections in the macrolithological division *k* and continues upwards to the top of the *Vaginatum* limestone. It is, as in the Siljan district, nearly always partly decomposed into hydrous ferric oxide.

4. In the lower part of the "*Raniceps*" limestone (div. *j*) non-glauconitic internal moulds of small shells of different groups of animals occur in the insoluble residue and thenceforward they form a characteristic component of the insoluble residue right to the top of the *Vaginatum* limestone. Small amounts of non-glauconitic internal moulds appear, however, already in the uppermost part of division *f*. These internal moulds certainly consist in part of chamosite, a part of them has probably been formed by phosphorite.

5. Pyrites has been observed mainly in very small quantities through almost the whole portion of the core studied. In the *Planilimbata* calcilutite (div. *a–b*) and the lowermost part of division *c* the contents of pyrites are comparatively large.

6. In the reddish brown limestones of division *d* and some parts of div. *m*, most of the iron seems to occur in the form of ferric oxide. In divisions *f–i* the iron contents are roughly proportional to the abundance of glauconite and seem to a large extent to be bound in this iron silicate. Some of the iron in divisions *k–m* is included in chamosite and in the lowermost beds of the section in pyrites. Generally, however, the sulphur contents of the limestones studied are very low (cf. Text Fig. 14), and in limestones of dominating grey colour only a small amount of iron occurs as sulphide.

Appendix

Table I

Horizon	Material soluble in dilute acetic acid (~$CaCO_3$) %	Horizon	Particle size of the limestone
23.47–23.53 m	93.3	23.48–23.56 m	37.0 %
23.96–24.02 m	92.9	23.96–24.02 m	Recrystallized
24.50–24.56 m	89.8	24.50–24.56 m	28.0 %
25.03–25.08 m	93.2	24.97–25.03 m	Recrystallized
25.43–25.48 m	94.8	25.48–25.52 m	40.0 %
25.94–26.00 m	94.3	26.00–26.05 m	Recrystallized
26.51–26.56 m	87.4	26.50–26.56 m	,,
26.92–26.99 m	93.5	26.99–27.04 m	,,
27.42–27.49 m	92.0	27.42–27.49 m	,,
28.01–28.06 m	93.5	27.96–28.01 m	,,
28.43–28.48 m	88.7	28.48–28.55 m	,,
28.95–29.00 m	93.1	29.00–29.03 m	,,
29.43–29.50 m	95.4	29.50–29.55 m	,,
29.97–30.02 m	91.6	29.97–30.02 m	,,
30.51–30.55 m	93.95	30.46–30.51 m	40.2 %
31.05–31.10 m	86.4	30.99–31.05 m	Recrystallized
31.40–31.46 m	59.0	31.46–31.53 m	,,
32.02–32.06 m	80.8	31.97–32.02 m	,,
32.40–32.47 m	91.5	32.47–32.52 m	,,
33.05–33.10 m	83.2	32.98–33.05 m	,,
33.46–33.51 m	85.3	33.46–33.51 m	,,
33.92–34.00 m	92.3	34.00–34.07 m	,,
34.53–34.57 m	94.0	34.47–34.53 m	34.0 %
35.01–35.06 m	88.8	34.97–35.01 m	19.4 %
35.44–35.50 m	87.8	35.50–35.57 m	15.1 %
36.03–36.09 m	87.5	35.98–36.03 m	18.6 %
36.44–36.50 m	87.1	36.50–36.54 m	12.5 %
36.98–37.05 m	76.4	36.98–37.05 m	17.9 %
37.52–37.57 m	86.5	37.46–37.52 m	9.9 %
37.99–38.09 m	80.4	37.99–38.04 m	10.9 %
38.51–38.58 m	64.7	38.44–38.51 m	1.9 %

Table II

Analyses of total iron as Fe_2O_3, total phosphorus as P_2O_5 and sulphur. Analyst J. LUKINS.

Horizon	Fe_2O_3	P_2O_5	S
23.5 m	1.98	0.13	0.03
24.0 m	2.07	0.13	0.04
24.5 m	1.98	0.31	0.05
25.0 m	1.80	0.09	0.01
25.5 m	2.34	0.09	0.02
26.0 m	2.16	0.24	0.05
26.5 m	1.98	0.09	0.06
27.0 m	1.44	0.97	0.04
27.5 m	3.24	0.13	0.03
28.0 m	2.70	0.35	0.02
28.5 m	2.52	0.24	0.03
29.0 m	2.16	0.69	0.03
29.5 m	2.52	0.21	0.02
30.0 m	2.34	0.82	0.02
30.5 m	1.80	0.40	0.07
31.0 m	3.42	0.54	0.07
31.5 m	6.84	1.12	0.01
32.0 m	4.68	0.64	0.02
32.5 m	3.78	0.78	0.02
33.0 m	2.16	0.36	0.02
33.5 m	1.80	0.44	0.04
34.0 m	2.16	0.26	0.04
34.5 m	2.52	0.11	0.02
35.0 m	3.26	0.10	tr.
35.5 m	2.60	0.05	0.02
36.0 m	3.06	0.17	tr.
36.5 m	3.60	0.06	0.02
37.0 m	3.42	0.11	0.02
37.5 m	3.35	0.08	0.22
38.0 m	2.70	0.09	0.20
38.5 m	3.60	0.16	0.20
39.0 m	2.88	0.09	0.35

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Plate I

Polished sections through core. — *Gigas* limestone showing in 1 a fairly regular alternation of red and grey limestone. In 2, which follows below 1, the distribution of red and grey is more irregular, only at *D* a marked deepening of the red colour coincides with a bedding plane. × 2/3. (The greater width of the lower part of 1 is due to the section lying nearer the centre of the core.)

Plate II

Polished sections through core. — *1*, *Lepidurus* limestone with white upper contact surfaces of the beds (*A-F*). *2*, Contact between the *Lepidurus* and *Limbata* limestones (at 34.86). *3*, *Limbata* limestone. Alternating red and grey limestone. In the 6.5 cm, which were left out, the limestone is grey. *1—3* × 2/3.

Plate III

Fig. 1. ?*Cheirurus* sp. Posterior part of pygidium from below. *Gigas* limestone, N. of Långalvaret. × 1 ½. U.M. Nr. Ar. 4223.

Fig. 2. *Pliomera* cf. *fischeri* (EICHW.) Hypostome. *Gigas* limestone Enerum. × 3. U.M. Nr. Ar. 4224.

Fig. 3. *Cyrtometopus clavifrons* (DALMAN). Cranidium. ?*Lepidurus* limestone. Gillberga. × 1. U.M. Nr. Ar. 4220.

Fig. 4. *Cyrtometopus* sp. Cranidium. *Gigas* limestone. N. of Långalvaret. × 1½. U.M. Nr. Ar. 4221.

Figs. 5—7. *Aristoharpes*? *rotundus* n. sp. Cranidium. Upper »*Raniceps*» limestone. Gunnarslund. U.M. Nr. Ar. 4225. — Fig. 5. Front view. × 6. — Fig. 6. From above. × 8. — Fig. 7. Side view. × 6.

Fig. 8. *Megalaspis* sp. Cranidium (cf. SCHMIDT 1906, Pl. VII, Fig. 2). *Gigas* limestone. Gunnarslund. × 1 ½. U.M. Nr. Ar. 4217.

Fig. 9. *Megalaspis* aff. *gigas* ANG. Cranidium. *Gigas* limestone. N. of Långalvaret. × 1. U.M. Nr. Ar. 4218.

Fig. 10. *Megalaspis hyorrhina* v. LEUCHTENB. Cranidium. *Lepidurus* limestone, Böda (boring, 33.55 m). × 1 ½. U.M. Nr. Ar. 4219.

Plate IV

Figs. 1—2. *Megalaspis obtusicauda* n. sp. Holotype. Pygidium, partly with corroded shell. *Obtusicauda* limestone. Gunnarslund. — Fig. 1. From above. — Fig. 2. Side view. × 1. U.M. Nr. Ar. 4215.

Fig. 3. *Megalaspis gigas* ANG. Lectotype. Pygidium without the shell. Riksmuseum, Stockholm N:r Ar. 21 770. × 1.

Fig. 4. *Megalaspis gigas* ANG. Pygidium without the shell. Enerum. U.M. Nr. Ar. 4214. × 1.

Fig. 5. *Asaphus* (*Neoasaphus*) *sulevi* cf. *knyrkoi* FR. SCHM. Cranidium. *Obtusicauda* limestone. Marsjö (Föra). × 3. U.M. Nr. Ar. 4226.

Plate V

Fig. 1. ?*Megalaspis limbata* var. Pygidium. *Limbata* limestone. Böda (boring, level 37.40 m). × 2. U.M. Nr. Ar. 4246.

Fig. 2. *Pseudasaphus duplicatus* n. sp. Holotype. Pygidium without the shell (doublure prepared on the right side). Upper »*Raniceps*» limestone. Gunnarslund. × 1 ½. U.M. Nr. Ar. 4239.

Figs. 3—5. *Pseudasaphus perstriatus* n. sp. Pygidia. *Gigas* limestone. — Fig. 3. Holotype (doublure prepared anteriorly on the left side). Böda (boring, level 23.60. U.M. Nr. Ar. 4240.) × 1 ½. — Fig. 4. Small specimen with partly preserved shell. Gunnarslund. U.M. Nr. Ar. 4241. × 1 ½. — Fig. 5. Specimen without the shell (doublure partly prepared to the left). N. of Långalvaret. × 1 ½. U.M. Nr. Ar. 4244.

Fig. 6. ?*Pseudasaphus* sp. Free cheek from below. *Gigas* limestone. N. of Långalvaret. × 1 ½. U.M. Nr. Ar. 4245.

Fig. 7. *Pseudasaphus duplicatus* n. sp. Partial free cheek (doublure prepared). Upper »*Raniceps*» limestone. Marsjö (Föra). U.M. Nr. Ar. 4236. × 1 ½.

Fig. 8. *Ptychopyge excavato-zonata*. ANG. Pygidium. *Lepidurus* limestone. Böda (boring, 32.25 m). × 1 ½. U.M. Nr. Ar. 4247.

Plate VI

Figs. 1—2. *Pseudasaphus perstriatus* n. sp. Cranidia. *Gigas* limestone. Gunnarslund. × 1 ½. — Fig. 1. U.M. Nr. Ar. 4242; Fig. 2. U.M. Nr. Ar. 4243.

Figs. 3—4. *Pseudasaphus duplicatus* n. sp. Cranidia. Upper »*Raniceps*» limestone. — Fig. 3. Posterior part with the shell. Sandvik (Persnäs) U.M. Nr. Ar. 4237. × 1 ½. — Fig. 4. Without the shell. Marsjö (Föra). × 1 ½. U.M. Nr. Ar. 4238.

Figs. 5—9. *Niobe frontalis* (Dalman). *Gigas* limestone. — Figs. 5—7. Cranidia. Fig. 5: Without the shell. N. of Långalvaret. U.M. Nr. Ar. 4234. Fig. 6: Shell partly preserved. Gunnarslund. U.M. Nr. Ar. 4233. Fig. 7: Shell almost complete. Gunnarslund. U.M. Nr. Ar. 4249. — Fig. 8 and 9. Pygidia. Fig. 8: N. of Långalvaret. U.M. Nr. Ar. 4231. Fig. 9: Södvik. U.M. Nr. Ar. 4232. Figs. 5—9 × 2.

Fig. 10. *Niobe* cf. *frontalis* (DALMAN). Pygidium with the shell. Red »*Asaphus* limestone». Lenstad. × 4. U.M. Nr. Ar. 4235.

Figs. 11—12. *Niobe imparilimbata* n. sp. ?*Limbata* limestone. Böda boring, 37.40 m × 2. — Fig. 11. Partial free cheek. × 2. U.M. Nr. Ar. 4229. — Fig. 12. Holotype. Pygidium with the shell. U.M. Nr. Ar. 4230.

Plate VII

All figures enlarged 40 ×. Photo N. HJORTH.

Fig. 1. Calcarenite. *Gigas* limestone, division *m*, at the level 25.48—25.52 m of the core.

Fig. 2. Slightly recrystallized calcarenite with subangular fossil fragments. »*Raniceps*» limestone, division *j*, at the level 30.46—30.51 m.

Fig. 3. Calcilutite rich in shell debris (calcarenaceous calcilutite). Intensely reddish brown *Limbata* limestone, division *d*, at the level 34.97—35.01 m.

Fig. 4. Calcilutite. Lowermost part of the *Limbata* limestone, division *c*, at the level 37.99—38.04 m.

Plate VIII

All figures enlarged 40 ×. Photo N. HJORTH.

Fig. 1. Strongly recrystallized calcarenite. »*Raniceps*» limestone, division *j*, at the level 27.95—28.01 m of the core.

Fig. 2. Calcarenite with a single rounded glauconite grain (g). »*Raniceps*» limestone, division *j*, at the level 29.00—29.03 m.

Fig. 3. Recrystallized calcarenite very rich in glauconite. The photo shows a spot particularly rich in glauconite in the thin section. *Expansus* limestone, division *g*, 31.46—31.53 m.

Fig. 4. Recrystallized calcarenite rich in glauconite. In the right upper corner an Echinoderm fragment with cavities filled with glauconite. *Lepidurus* limestone, division *f*, 32.98—33.05 m.

Plate IX

Glauconite grains from the insoluble residue, fraction 0.5—0.25 mm.

All figures enlarged 10×. Photo N. HJORTH.

Fig. 1. Rounded glauconite grains. »*Raniceps*» limestone, division *j*, at the level 29.5 m of the core.

Fig. 2. Rounded glauconite grains. *Expansus* limestone, division *i*, at the level 31.0 m of the core.

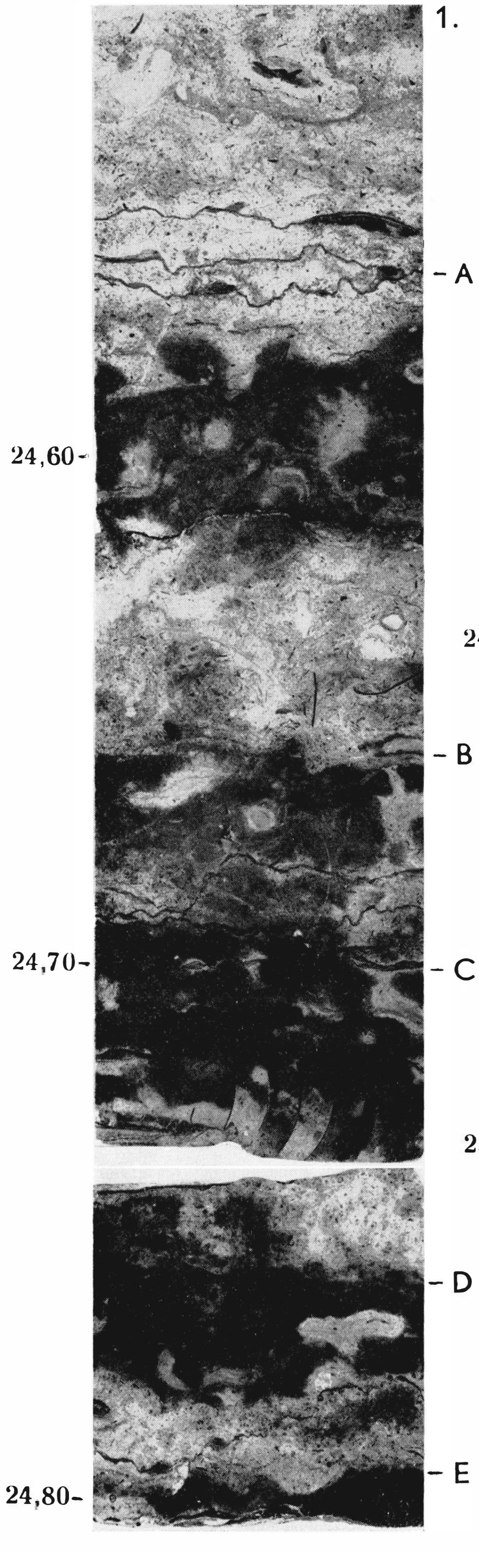
Fig. 3. Angular glauconite grains. *Lepidurus* limestone, division *f*, at the level 32.0 m of the core.

Fig. 4. Angular glauconite grains. *Lepidurus* limestone, division *f*, at the level 33.5 m of the core.

Plate X

Internal moulds of small shells from the insoluble residue.

Both figures enlarged 15×. Photo N. HJORTH.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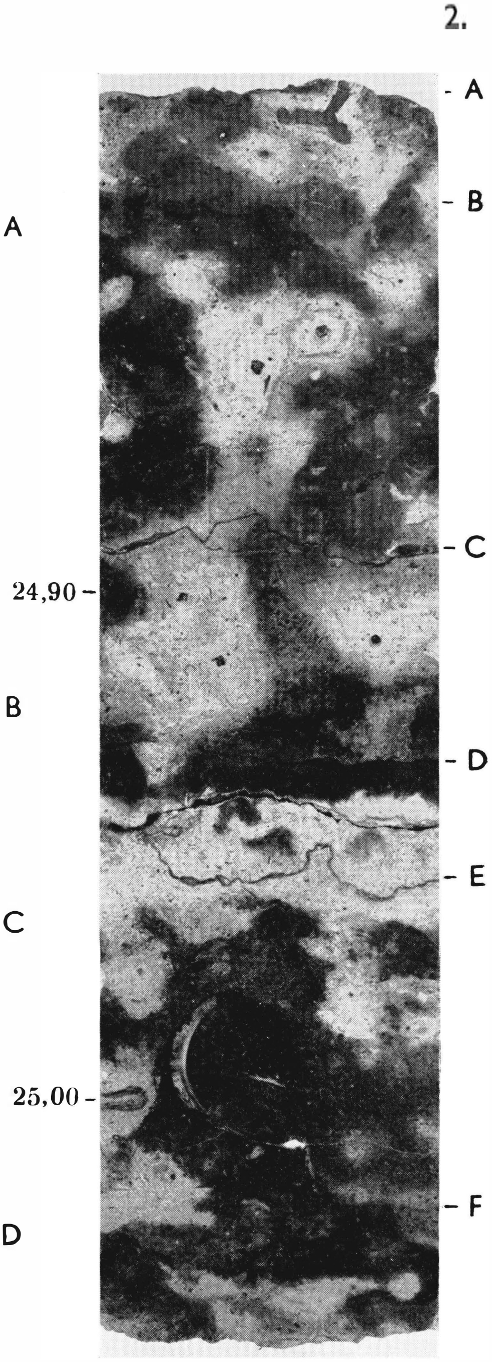
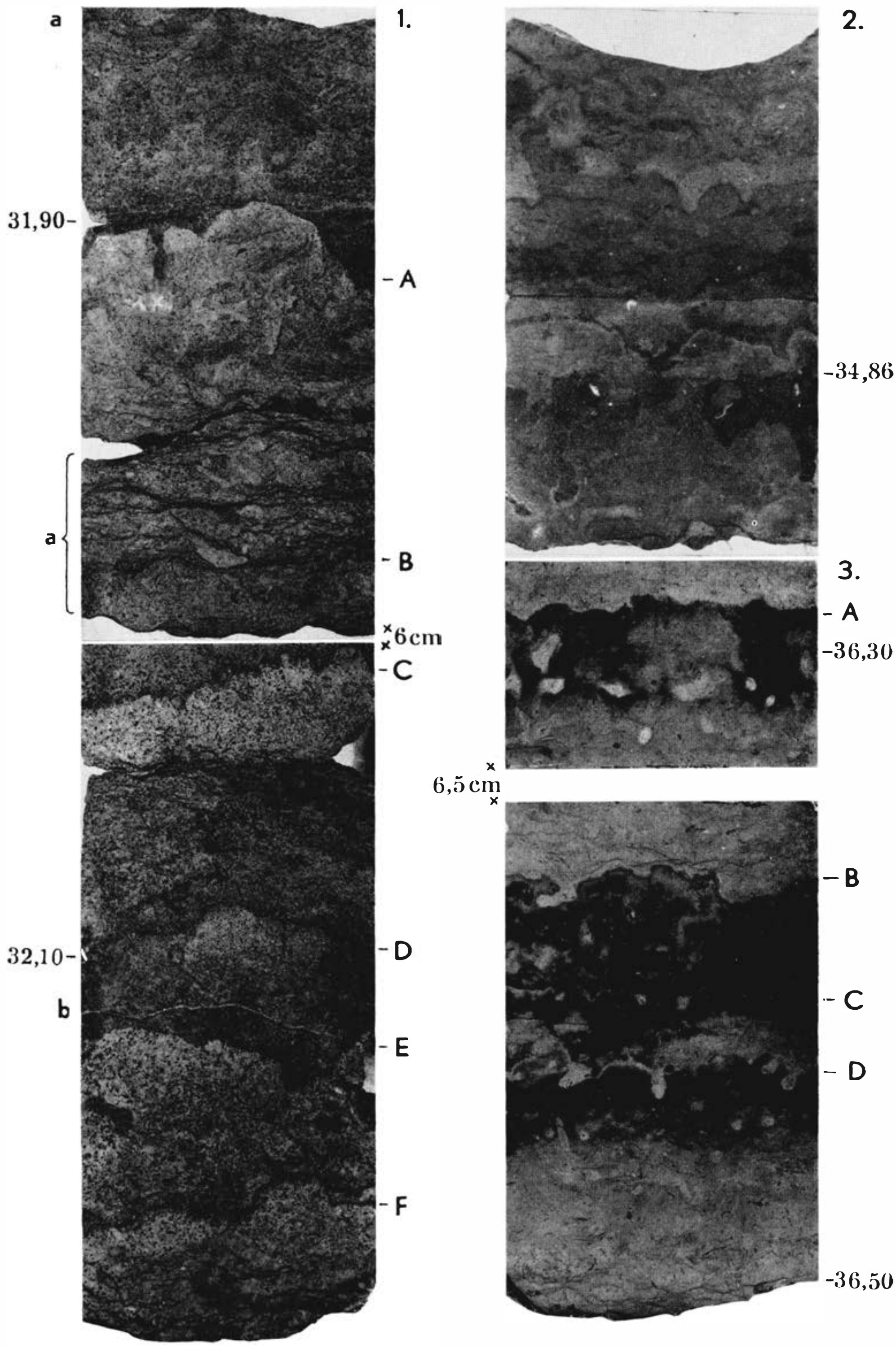
24,70
24,80
A
B
C
D
E


2.
24,90
25,00
A
B
C
D
E
F


1.
a
31,90-
-A
a
-B
6cm
-C
32,10-
-D
b
-E
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-C
-D
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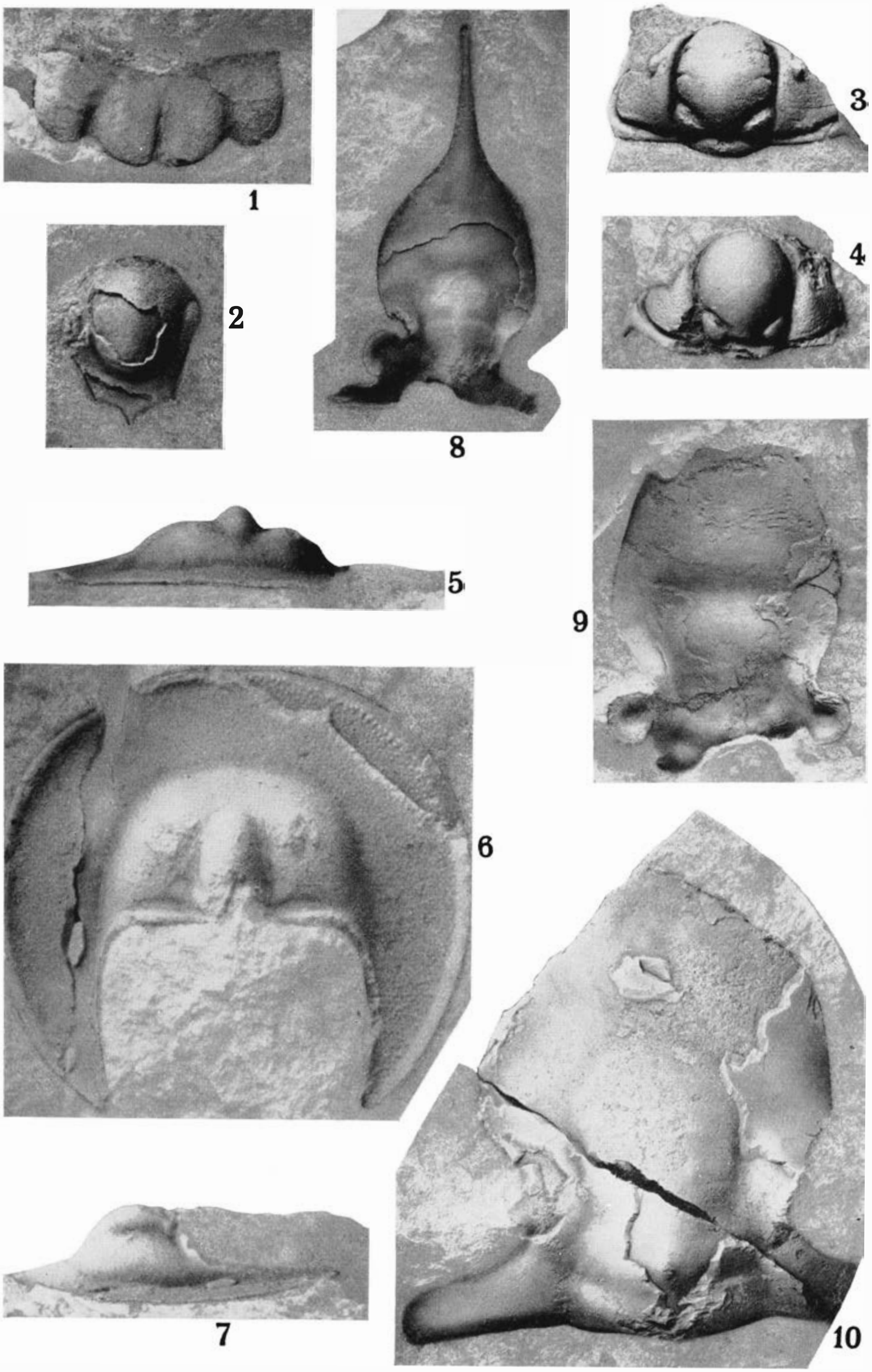
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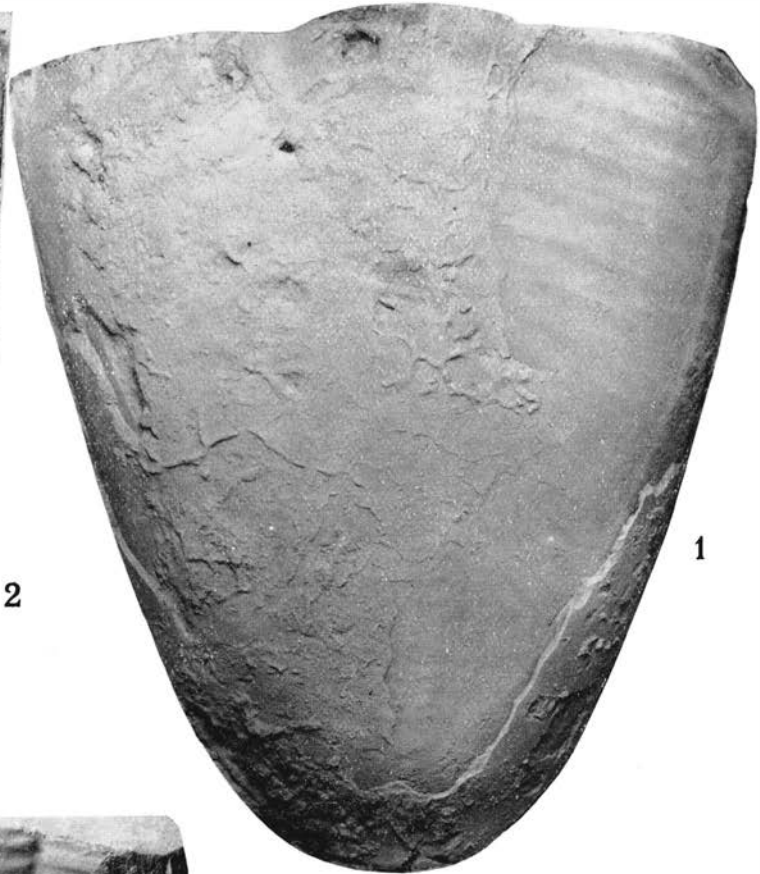

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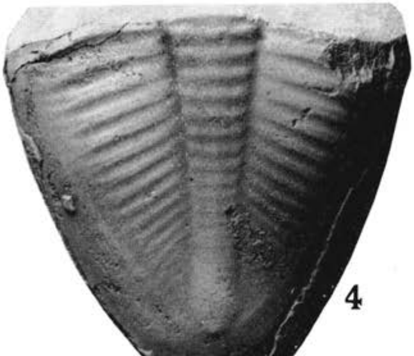

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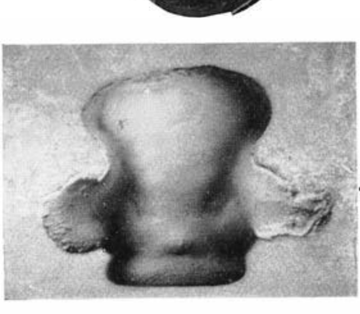

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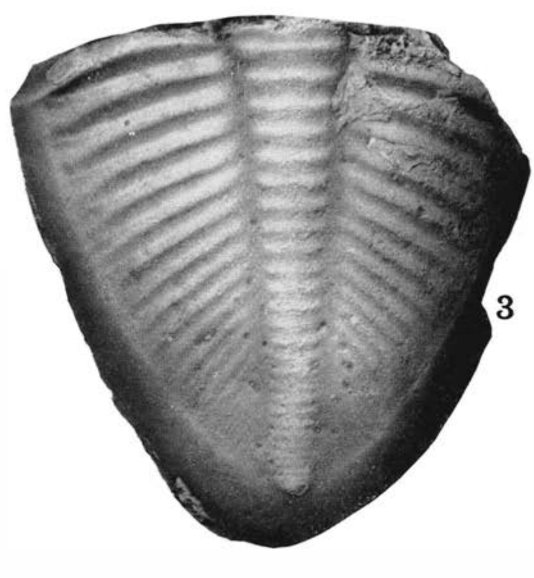

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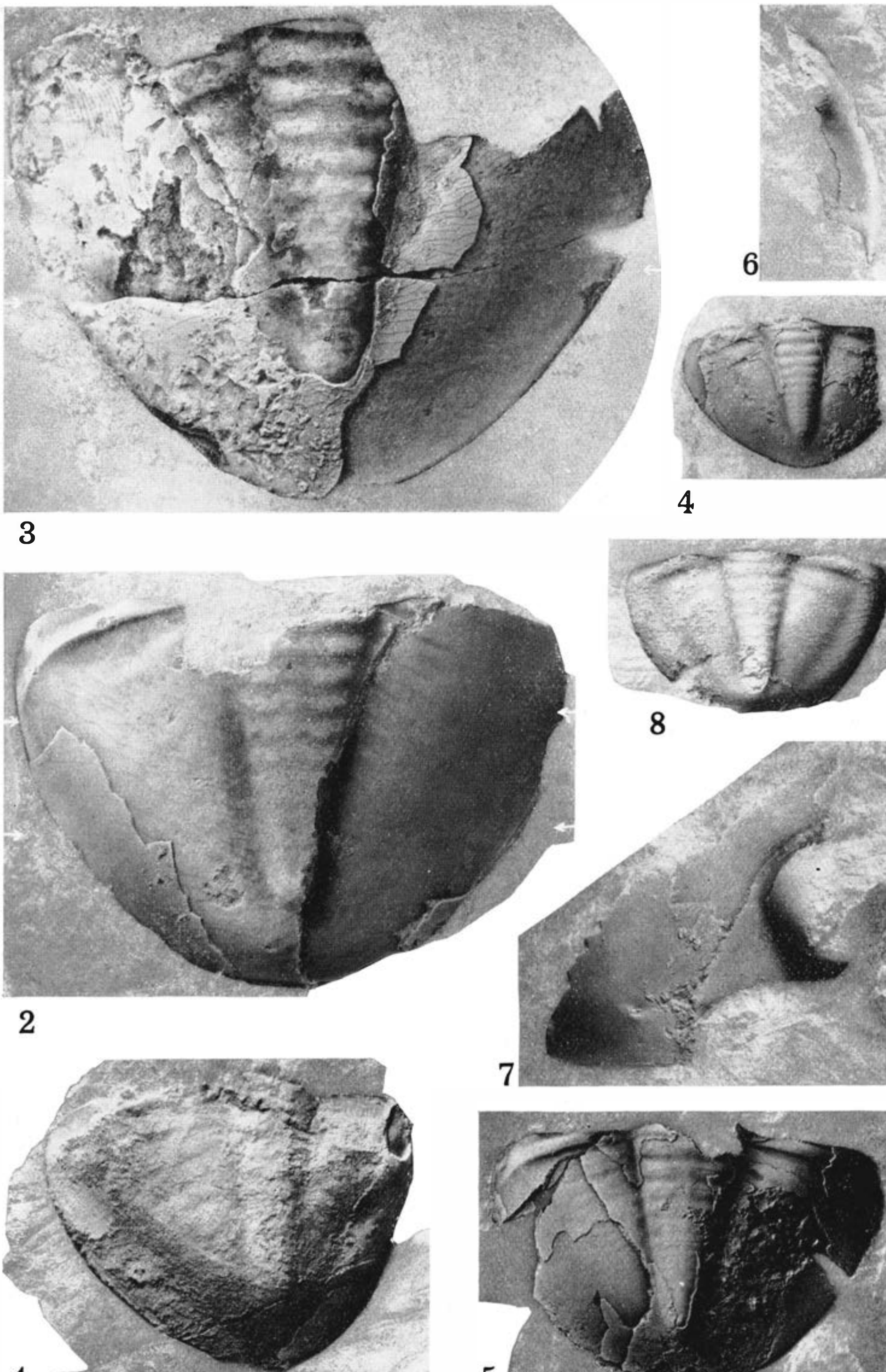
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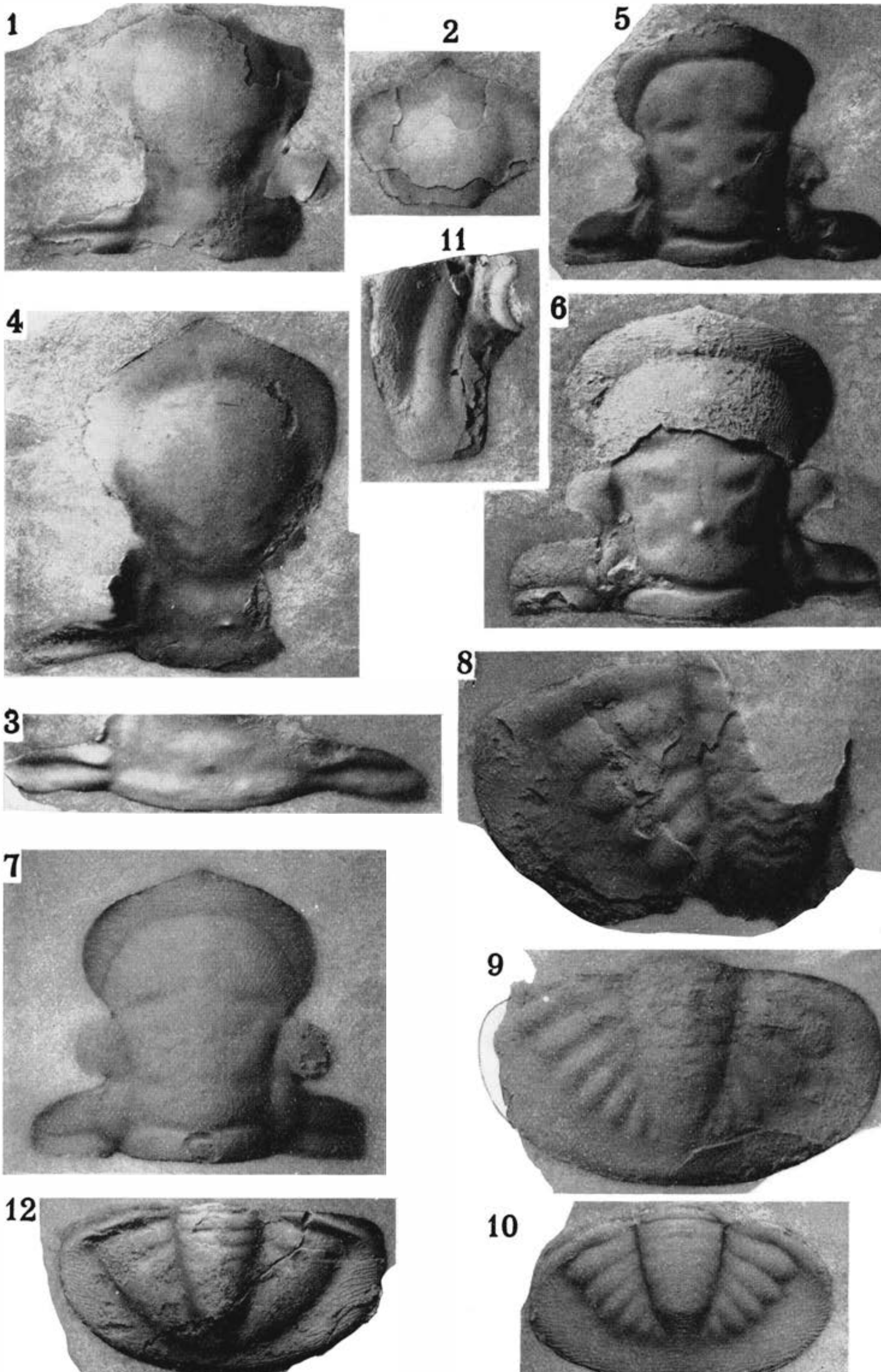
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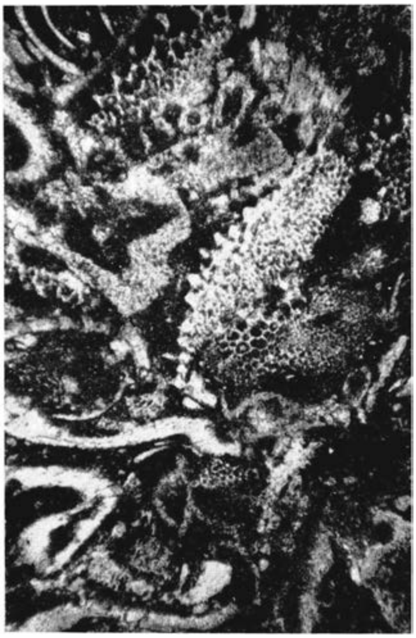

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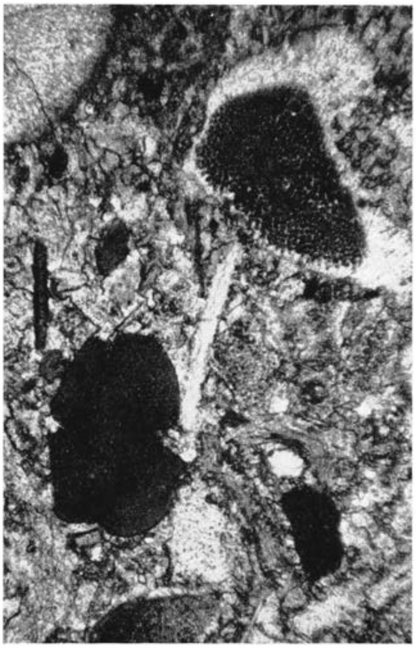

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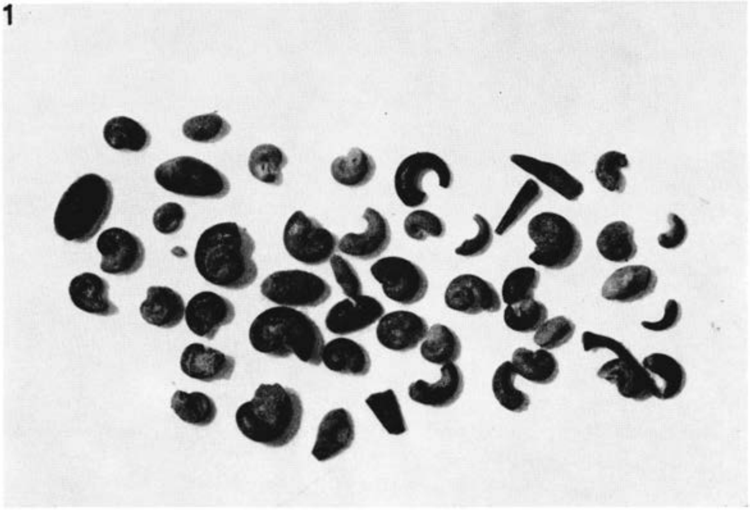

Fig. 1. Non-glauconitic internal moulds from the *Gigas* limestone. Division *m*, at the level 23.5 m of the core.

2

Fig. 2. Glauconitic internal moulds from the *Lepidurus* limestone. Division *f*, at the leve 34.0 m of the core.